National Aeronautics and
Space Administration

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

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Table of Contents

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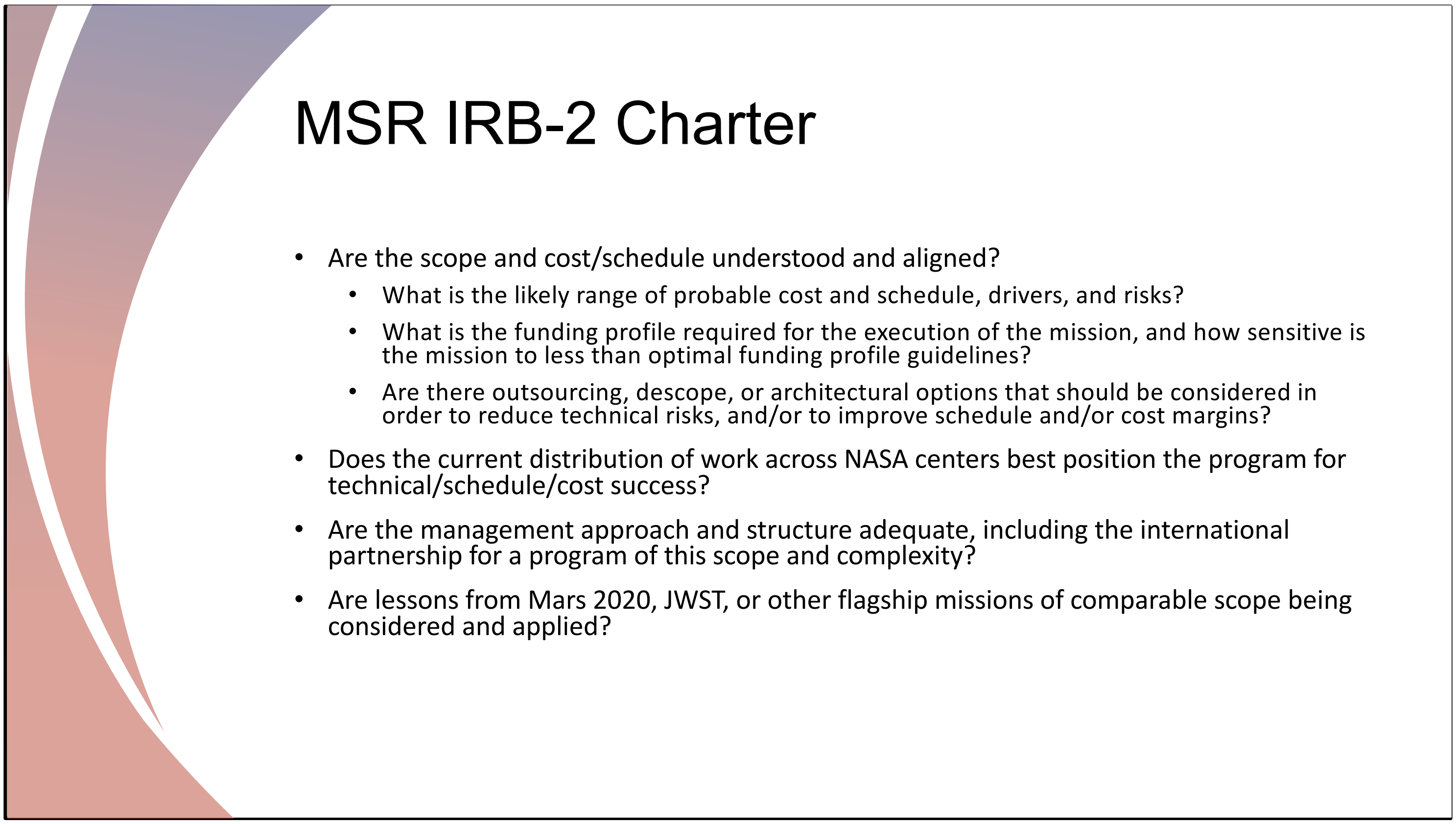


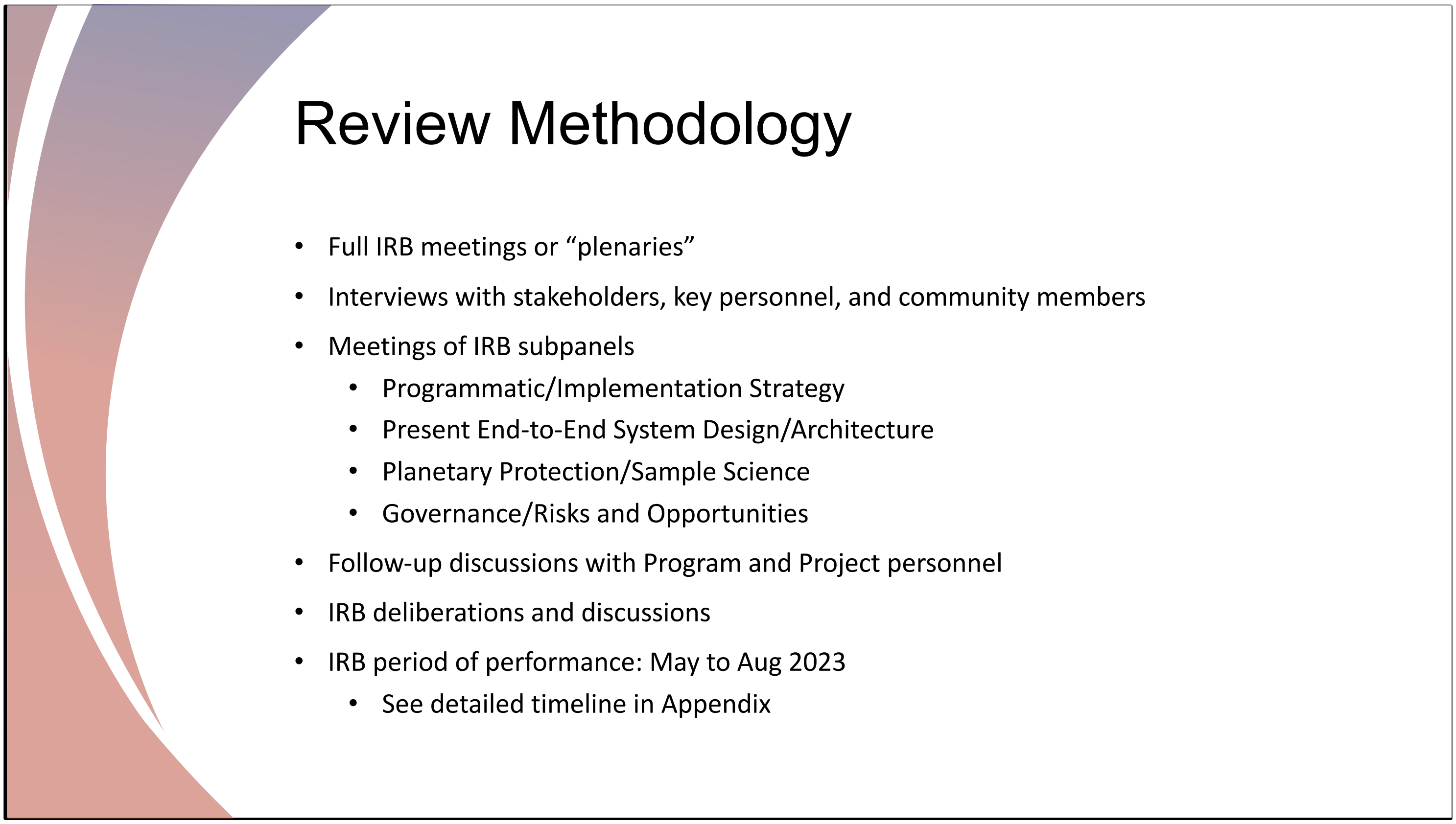
MSR IRB-2 Charter

- Are the scope and cost/schedule understood and aligned?
  - What is the likely range of probable cost and schedule, drivers, and risks?
  - What is the funding profile required for the execution of the mission, and how sensitive is the mission to less than optimal funding profile guidelines?
  - Are there outsourcing, descope, or architectural options that should be considered in order to reduce technical risks, and/or to improve schedule and/or cost margins?
- Does the current distribution of work across NASA centers best position the program for technical/schedule/cost success?
- Are the management approach and structure adequate, including the international partnership for a program of this scope and complexity?
- Are lessons from Mars 2020, JWST, or other flagship missions of comparable scope being considered and applied?

The IRB was able to address the elements of the charter thanks to the extraordinary level of expertise and commitment from a broad and diverse membership. The following two elements are addressed indirectly (i.e., they have no specific Findings/Recommendations), but are reflected in one or more findings.

Outsourcing: Evaluation by the IRB focused on the adequacy of the plans, required expertise (i.e., skills and experience), and the risks associated with implementation of existing contracts. MSR is a very complex mission that requires unique and proven expertise for successful development. The IRB took the validity of the two NASA Acquisition Strategy Meetings (ASM) at face value in this approach. Alternate architectures may offer an opportunity to revisit the acquisition strategy for some of the elements or components of the architecture. Evaluation of the possible sources must show credible and assured availability for mission success as part of a NASA ASM-level review.

Lessons learned: lessons such as assembling a team of the best people talent available, and actions to deal with long lead hardware and critical path items to reduce risk are being applied effectively. The latter is more important now than ever to deal with supply chain and lingering post pandemic issues. The larger and most consequential lessons noted in the Large Mission Study conducted by NASA/SMD have not or were not applied, specifically: Unacknowledged or undeclared uncertainties associated with early estimates, Ineffective system of checks and balances, Underestimated impact of recurring system design changes.



Review Methodology

- Full IRB meetings or “plenaries”
- Interviews with stakeholders, key personnel, and community members
- Meetings of IRB subpanels
  - Programmatic/Implementation Strategy
  - Present End-to-End System Design/Architecture
  - Planetary Protection/Sample Science
  - Governance/Risks and Opportunities
- Follow-up discussions with Program and Project personnel
- IRB deliberations and discussions
- IRB period of performance: May to Aug 2023
  - See detailed timeline in Appendix

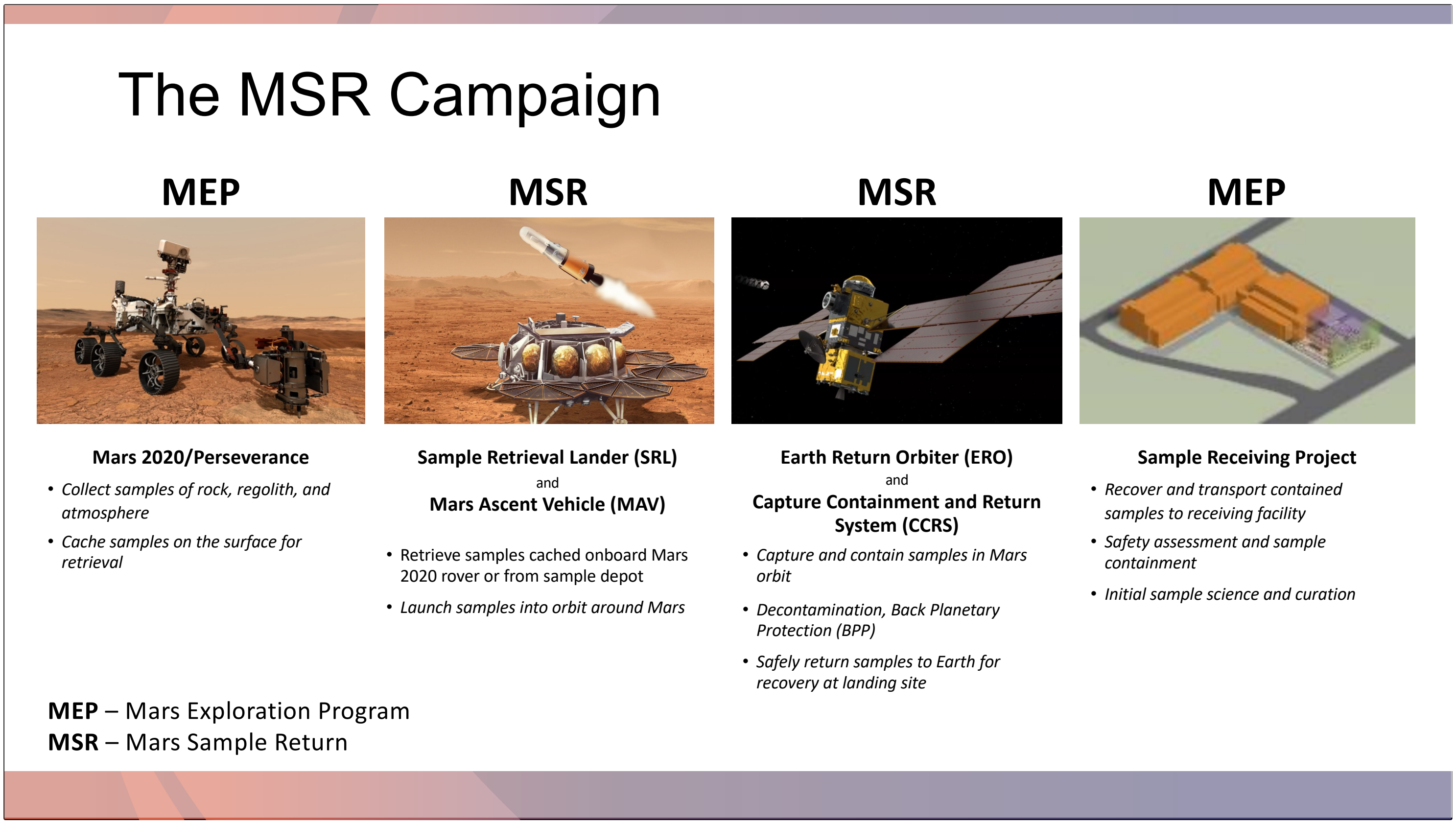
The IRB spent considerable time and effort in formal and informal settings in order to develop deep and common understanding of issues within the scope of the Charter. The complexities of MSR as a large, highly constrained, high-priority science flagship mission led the IRB to create subpanels in order to organize and be able to penetrate specific areas of concern ahead of discussions at Plenary sessions with the full IRB.

Individual members were also given specific assignments for follow-through on issues, and to develop thorough understanding on potential recommendations for discussion with the broader IRB.

MSR Background: Pre-Phase A to Present

- NASA acquisition strategies included multiple NASA Centers and a European Space Agency (ESA) partnership from the beginning of pre-Phase A, with ESA providing a Sample Fetch Rover (SFR)/Sample Transfer Arm and the Earth Return Orbiter (ERO)/Ariane launch vehicle. *The US cost was constrained to less than $3B.*
- Industrial pre-development contracts for ERO, the SFR, and the Ariane Launch Vehicle began shortly after the first (2019) of two NASA acquisition strategy meetings.
- NASA/SMD chartered an MSR IRB-1 in 2020 to inform Key Decision Point A (KDP-A). The IRB found the total program plans to be virtually non-executable.
- Re-baselining MSR to deal with mass and other issues highlighted by IRB-1 included consideration for a second lander for the SFR. This option was eventually rejected because of added complexity/cost.
- An opportunity for Italy to contribute a second lander was eliminated because of the need to re-baseline the ESA Rosalind Franklin Mars mission due to the Russian invasion of Ukraine.
- The success of the Ingenuity helicopter on Mars resulted in the baseline placing higher reliance on the Perseverance rover, with support by helicopters as backups. The SFR was descoped.
- A variety of mounting issues with the evolving baseline including technical, schedule, and cost concerns led to the creation of IRB-2.

Acquisition strategy meetings were held by NASA in July 2019 (pre KDP-A) and May 2021 (post KDP-A).



The MSR Campaign

MEP

Mars 2020/Perseverance

- *Collect samples of rock, regolith, and atmosphere*
- *Cache samples on the surface for retrieval*

MSR

Sample Retrieval Lander (SRL)
and
Mars Ascent Vehicle (MAV)

- Retrieve samples cached onboard Mars 2020 rover or from sample depot
- *Launch samples into orbit around Mars*

MSR

Earth Return Orbiter (ERO)
and
Capture Containment and Return System (CCRS)

- *Capture and contain samples in Mars orbit*
- *Decontamination, Back Planetary Protection (BPP)*
- *Safely return samples to Earth for recovery at landing site*

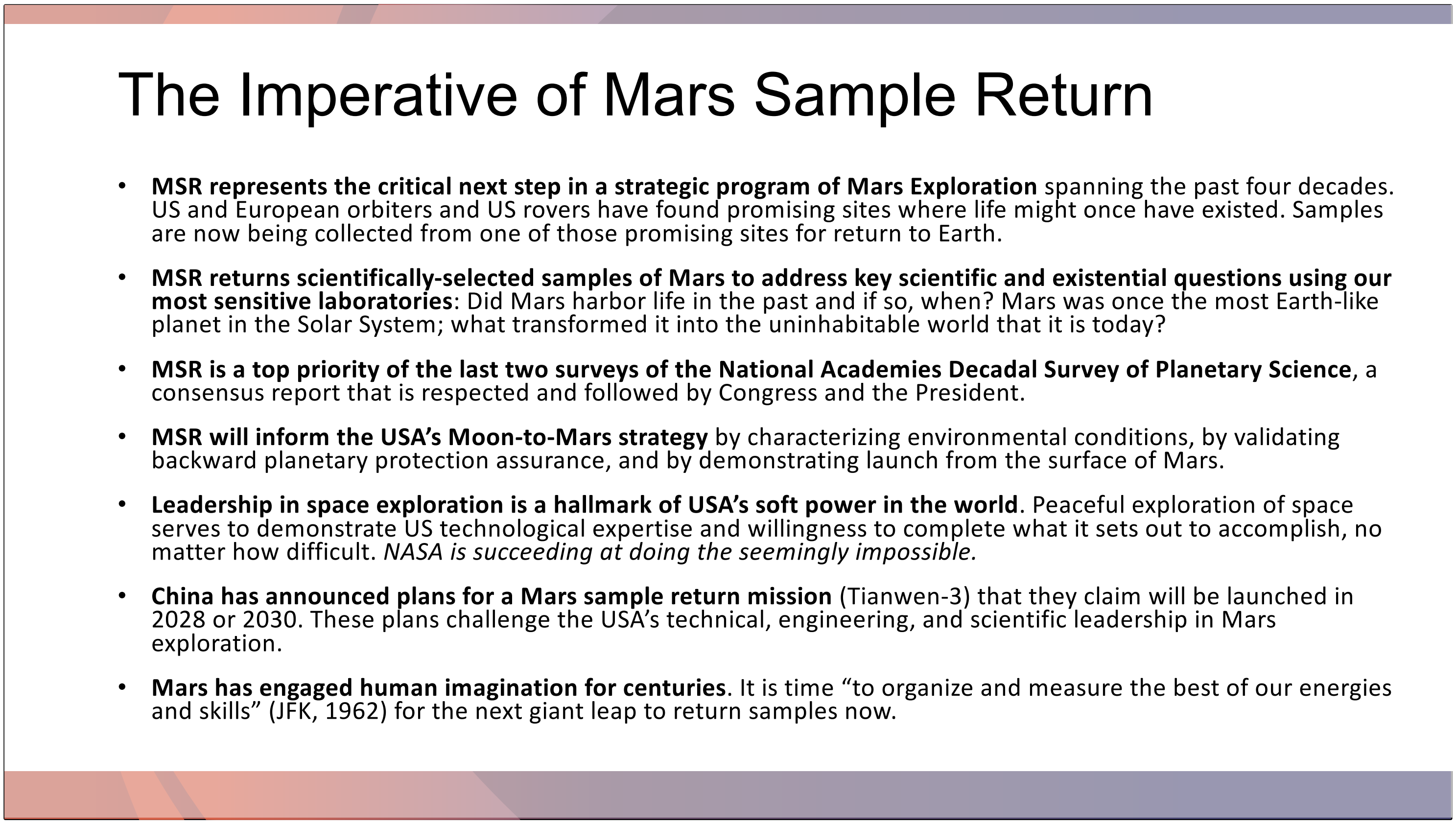
MEP

Sample Receiving Project

- *Recover and transport contained samples to receiving facility*
- *Safety assessment and sample containment*
- *Initial sample science and curation*

MEP – Mars Exploration Program
MSR – Mars Sample Return

The MSR campaign spans two important programmatic efforts: the Mars Exploration Program and the Mars Sample Return.



The Imperative of Mars Sample Return

- **MSR represents the critical next step in a strategic program of Mars Exploration** spanning the past four decades. US and European orbiters and US rovers have found promising sites where life might once have existed. Samples are now being collected from one of those promising sites for return to Earth.
- **MSR returns scientifically-selected samples of Mars to address key scientific and existential questions using our most sensitive laboratories**: Did Mars harbor life in the past and if so, when? Mars was once the most Earth-like planet in the Solar System; what transformed it into the uninhabitable world that it is today?
- **MSR is a top priority of the last two surveys of the National Academies Decadal Survey of Planetary Science**, a consensus report that is respected and followed by Congress and the President.
- **MSR will inform the USA's Moon-to-Mars strategy** by characterizing environmental conditions, by validating backward planetary protection assurance, and by demonstrating launch from the surface of Mars.
- **Leadership in space exploration is a hallmark of USA's soft power in the world**. Peaceful exploration of space serves to demonstrate US technological expertise and willingness to complete what it sets out to accomplish, no matter how difficult. *NASA is succeeding at doing the seemingly impossible.*
- **China has announced plans for a Mars sample return mission** (Tianwen-3) that they claim will be launched in 2028 or 2030. These plans challenge the USA's technical, engineering, and scientific leadership in Mars exploration.
- **Mars has engaged human imagination for centuries**. It is time "to organize and measure the best of our energies and skills" (JFK, 1962) for the next giant leap to return samples now.

NASA started conceptualization of a surface MSR idea after the successful Viking landers and what those landers discovered in the first two years of surface operations (1976-1978).

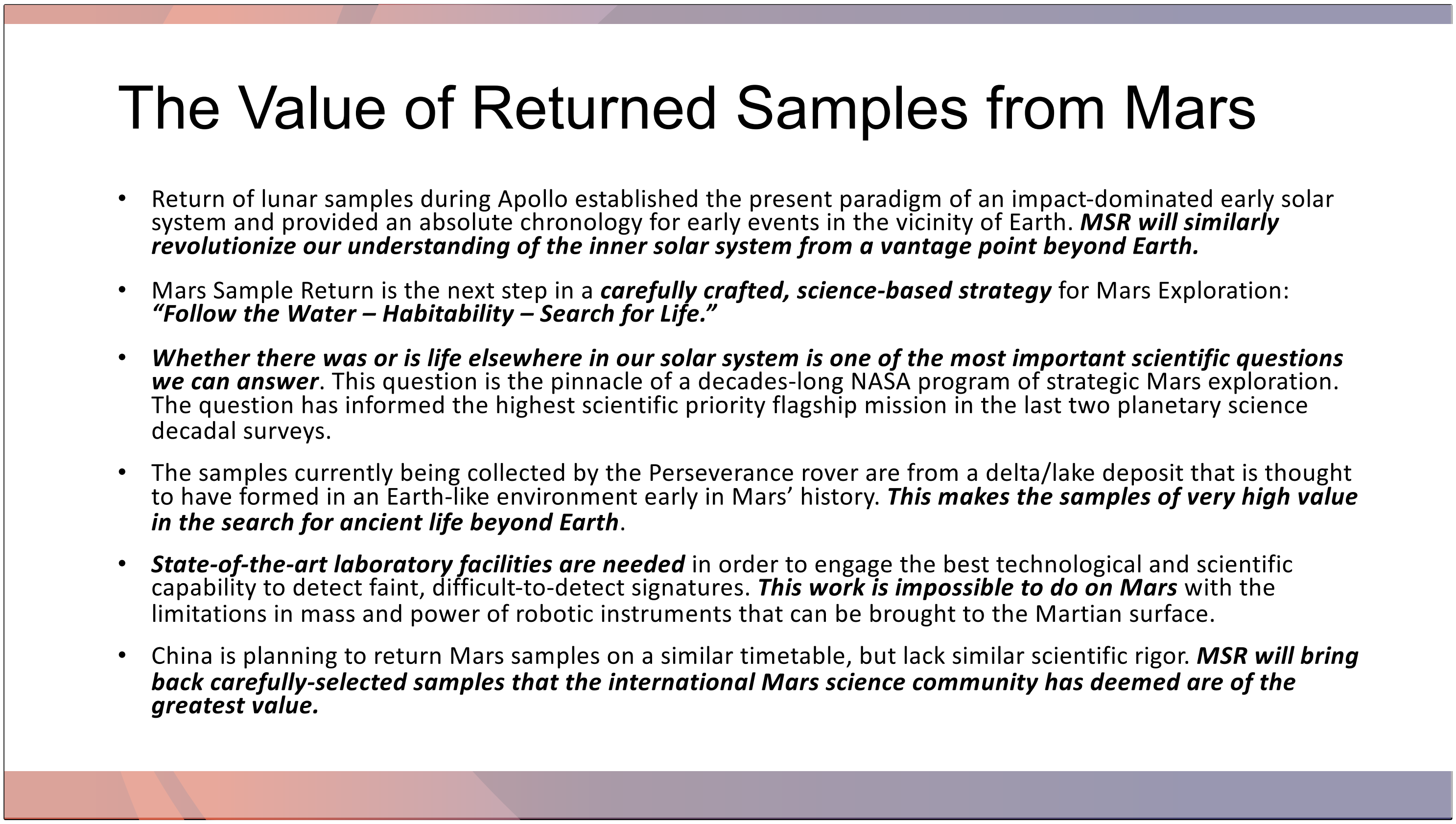
From 1988 through 1997, multiple concepts for a Mars rover sample return mission were considered as a flagship to follow orbital and surface exploration by Mars Observer and multiple spacecraft in the Mars Surveyor Program.

The Mars 1998 failures of MCO and MPL led NASA to charter an independent review of the Mars Program just as a National Academy of Sciences study commissioned by NASA called for multiple MSRs. The NASA response to the failures led to a new Mars Exploration Program and architecture as a standalone Program Office reporting to the NASA Science Associate Administrator.

The new Mars Exploration Program included MSR as a step beyond the initial core program composed of orbital reconnaissance orbiters/in-situ reconnaissance and sampling and preparations for eventual sample return. Over $20B has been invested across more than four decades to arrive at this moment.

"Soft power" or "getting what you want [in international relations] through attraction rather than coercion" is a benefit of NASA's human spaceflight programs." This is also true for dramatic planetary missions. [Pathways to Exploration (NRC, 2014)]

By abandoning return of Mars samples to other nations, the US abandons the preeminent role that JFK ascribed to the scientific exploration of space in his 1962 Rice U speech: "We set sail on this new sea because there is new knowledge to be gained, and new rights to be won, and they must be won and used for the progress of all people."

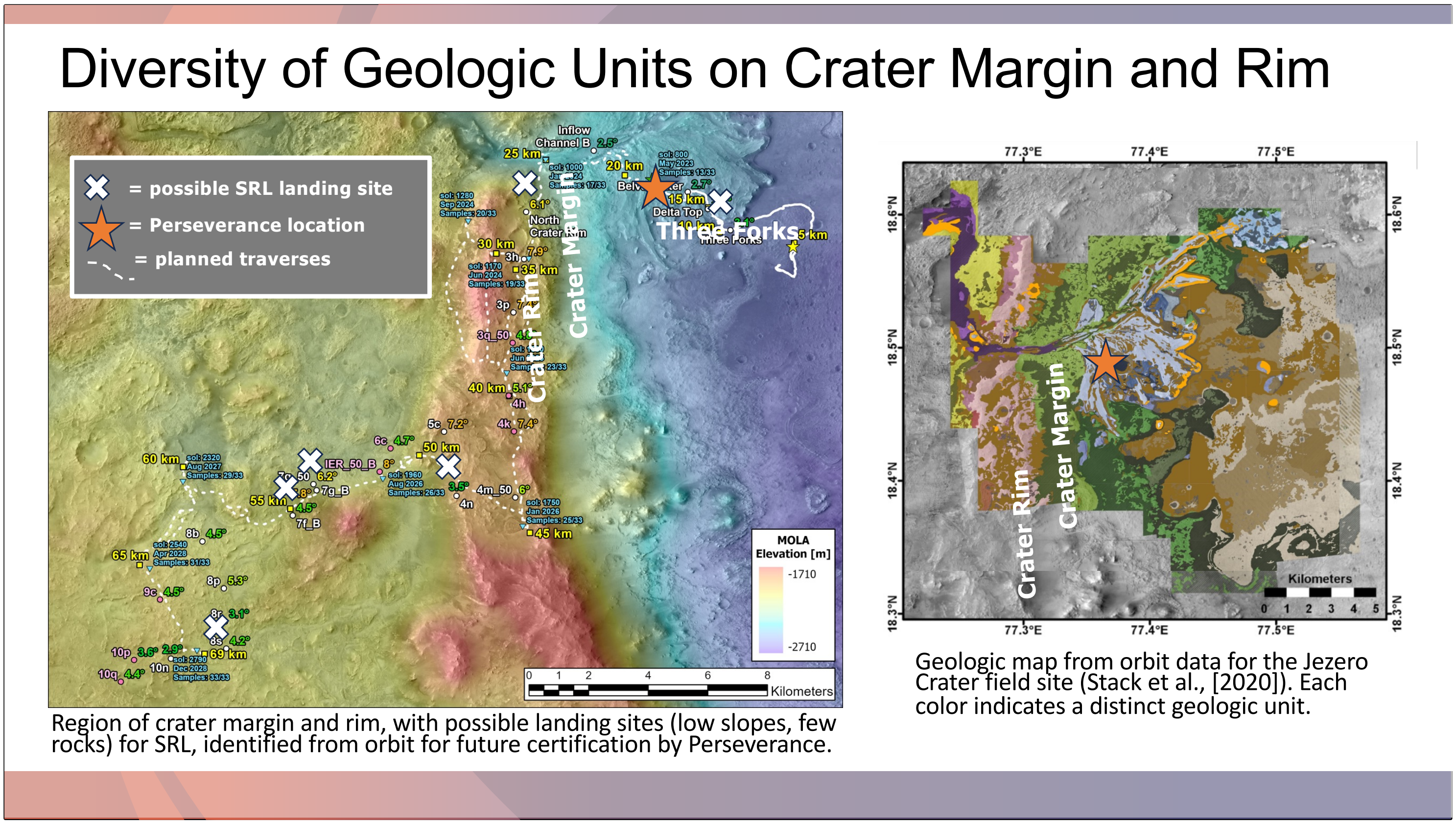


The Value of Returned Samples from Mars

- Return of lunar samples during Apollo established the present paradigm of an impact-dominated early solar system and provided an absolute chronology for early events in the vicinity of Earth. ***MSR will similarly revolutionize our understanding of the inner solar system from a vantage point beyond Earth.***
- Mars Sample Return is the next step in a ***carefully crafted, science-based strategy*** for Mars Exploration: ***"Follow the Water – Habitability – Search for Life."***
- ***Whether there was or is life elsewhere in our solar system is one of the most important scientific questions we can answer***. This question is the pinnacle of a decades-long NASA program of strategic Mars exploration. The question has informed the highest scientific priority flagship mission in the last two planetary science decadal surveys.
- The samples currently being collected by the Perseverance rover are from a delta/lake deposit that is thought to have formed in an Earth-like environment early in Mars' history. ***This makes the samples of very high value in the search for ancient life beyond Earth***.
- ***State-of-the-art laboratory facilities are needed*** in order to engage the best technological and scientific capability to detect faint, difficult-to-detect signatures. ***This work is impossible to do on Mars*** with the limitations in mass and power of robotic instruments that can be brought to the Martian surface.
- China is planning to return Mars samples on a similar timetable, but lack similar scientific rigor. ***MSR will bring back carefully-selected samples that the international Mars science community has deemed are of the greatest value.***

"Origins, Worlds and Life," the NAS Decadal Strategy for Planetary Science and Astrobiology, says "key scientific objectives for Mars and, more broadly, for planetary and astrobiological science, can only be achieved via study of carefully selected Martian samples in terrestrial laboratories … Certain types of measurements (e.g., phase-specific stable and radiogenic isotopes, trace elements, nanometer-scale composition and texture, and precise organics characterization) cannot be done remotely because they require sample preparations and analytical precisions only possible in specialized laboratories." (p. 22-7) The Decadal Strategy goes on to say (p. 22-8) "In addition, sample return will allow for future analyses by instruments and techniques not yet developed. As has been the case with the Apollo samples from the Moon, future analyses are expected to yield profound results for many decades after sample return."

The key science investigations enabled by improved and novel measurements of returned samples include (summarized from Decadal Strategy text 22-7, 22-8): the identification of potential biosignatures that are difficult to detect or are not accessible to in-situ measurements; a history of liquid water (where, how long?) at the Jezero site, and determining the absolute chronology of key events in the formation of Jezero from radioisotopic dating.



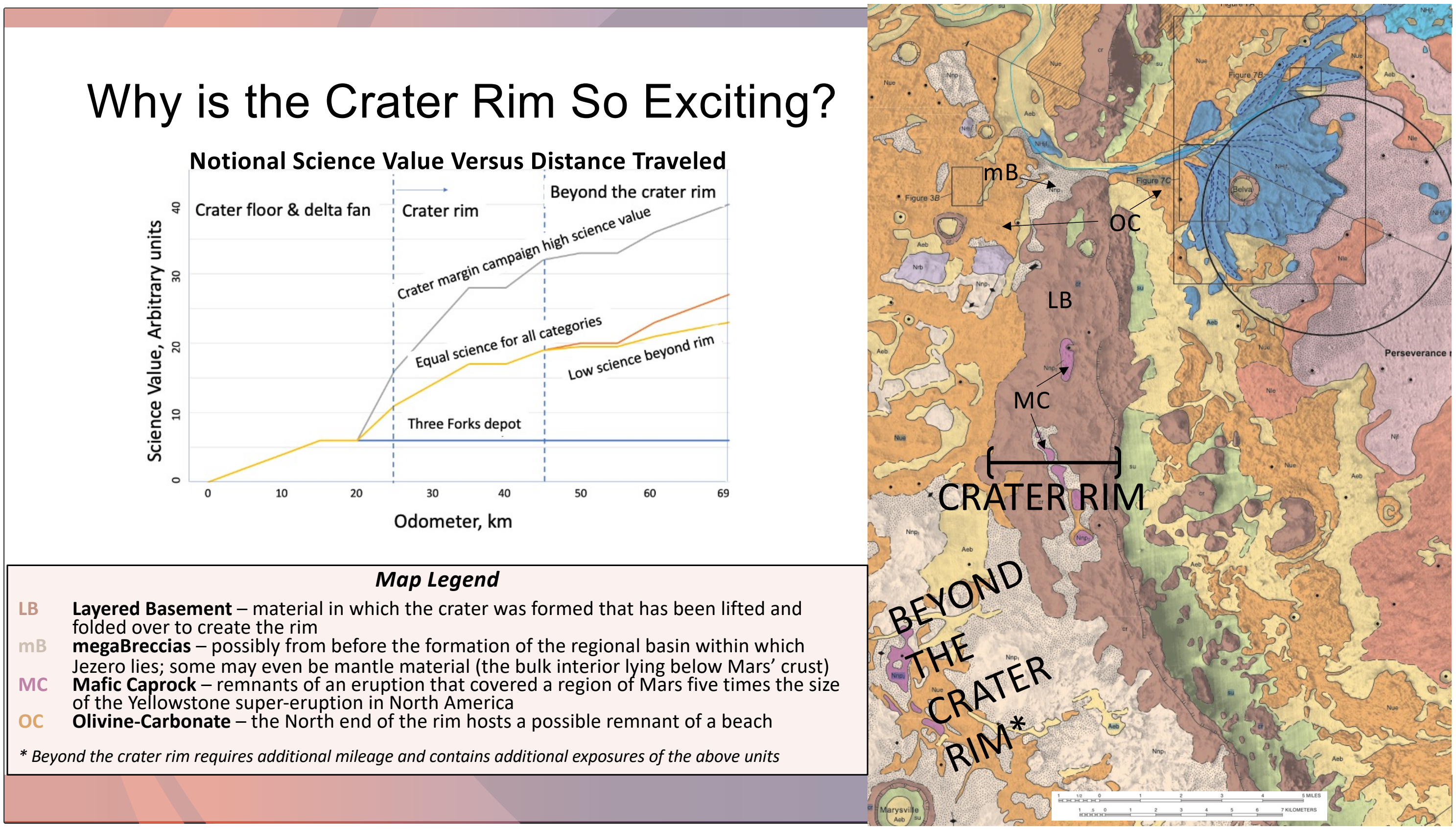
Diversity of Geologic Units on Crater Margin and Rim

Region of crater margin and rim, with possible landing sites (low slopes, few rocks) for SRL, identified from orbit for future certification by Perseverance.

Geologic map from orbit data for the Jezero Crater field site (Stack et al., [2020]). Each color indicates a distinct geologic unit.

The image on the left is colorized by elevation (red = high, blue = low) around the western rim of Jezero crater. The delta fan, Perseverance's approximate current location, and the Three Forks depot are located at top right. White dotted lines and "X"s indicate possible future drive paths and SRL landing sites.

A zoomed-in view of the delta fan and adjacent crater margin and rim is shown at right. The image is colorized according to the different geologic units that have been mapped in the area, revealing the tremendous diversity available for Perseverance to sample as it continues driving towards the west. The orange star indicates Perseverance's location.



Why is the Crater Rim So Exciting?

Map Legend

LB	**Layered Basement** – material in which the crater was formed that has been lifted and folded over to create the rim
mB	**megaBreccias** – possibly from before the formation of the regional basin within which Jezero lies; some may even be mantle material (the bulk interior lying below Mars' crust)
MC	**Mafic Caprock** – remnants of an eruption that covered a region of Mars five times the size of the Yellowstone super-eruption in North America
OC	**Olivine-Carbonate** – the North end of the rim hosts a possible remnant of a beach

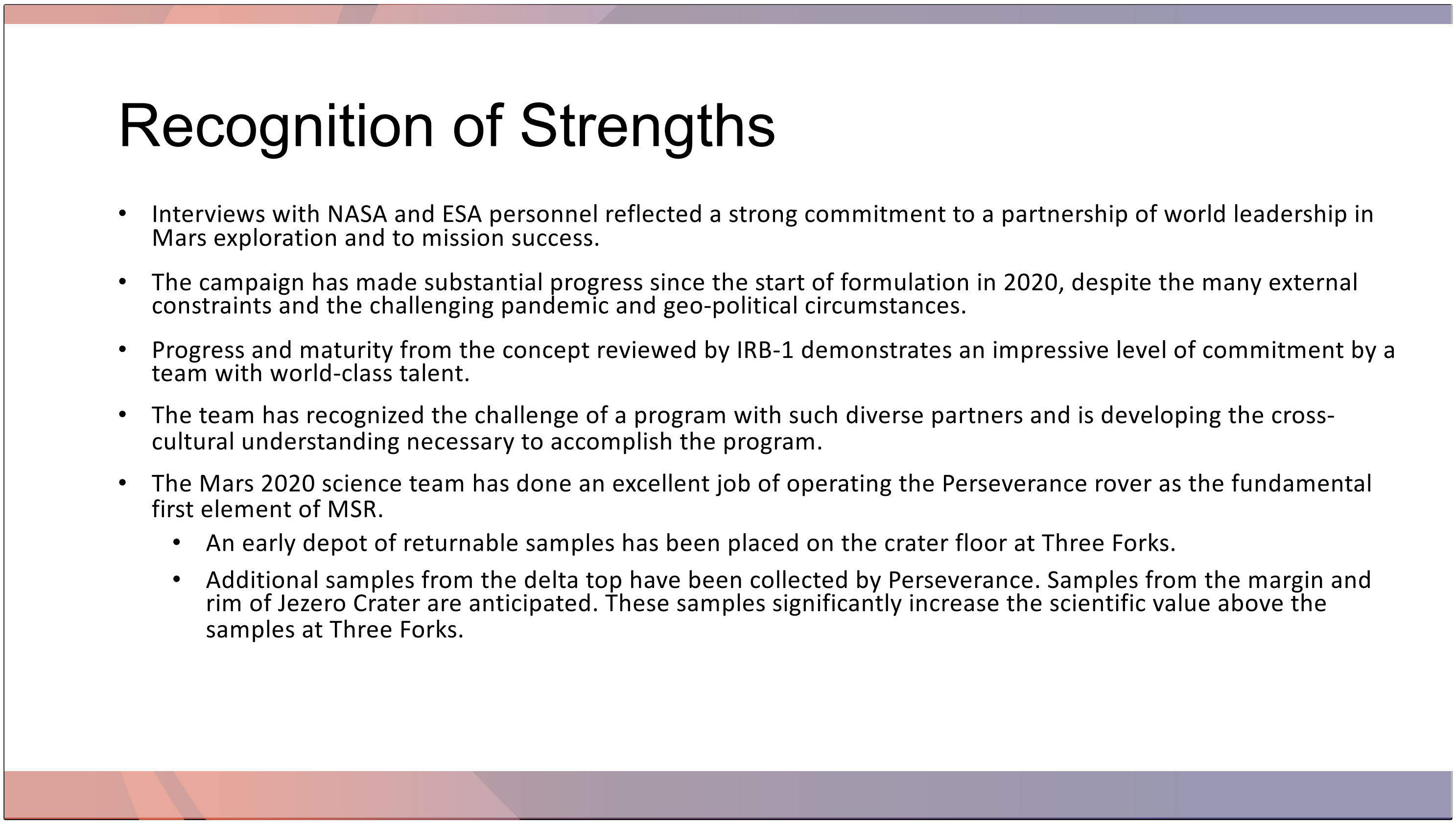
** Beyond the crater rim requires additional mileage and contains additional exposures of the above units*

This slide shows the relative scientific value of the Martian samples that would be returned to Earth based on the distance traveled by Mars 2020's Perseverance rover, categorized as: on the crater floor and delta fan, on the crater rim, and beyond the crater rim.

The 10 samples deposited at the Three Forks depot, which represent only the geology of the crater floor and front of the delta, are the only samples that would be returned to Earth in the first scenario. In this scenario, no additional value to Mars Sample Return is achieved from the continued exploration and collection of samples by Perseverance.

In all other scenarios, the samples to be returned to Earth are the ones that are already onboard and yet to be secured by Perseverance. The collection of additional samples yields increasing science value as Perseverance continues its trek along the delta top, across the crater margin, and then out of Jezero onto the crater rim. The differences in the lines on the graph lie in the scientific value assigned to each new sample — whether the value is equivalent to ("equal science") or greater ("high science value") than the samples already collected. Mars scientists suspect that the crater margin and rim contain material of exceptional diversity. The science value may hence increase more substantially in that part of the mission.

Once Perseverance reaches the region beyond the crater rim, there are ambiguities in our understanding of what Perseverance will encounter. The increase in science value may therefore be less than expected, but we will not know this until Perseverance gets there.



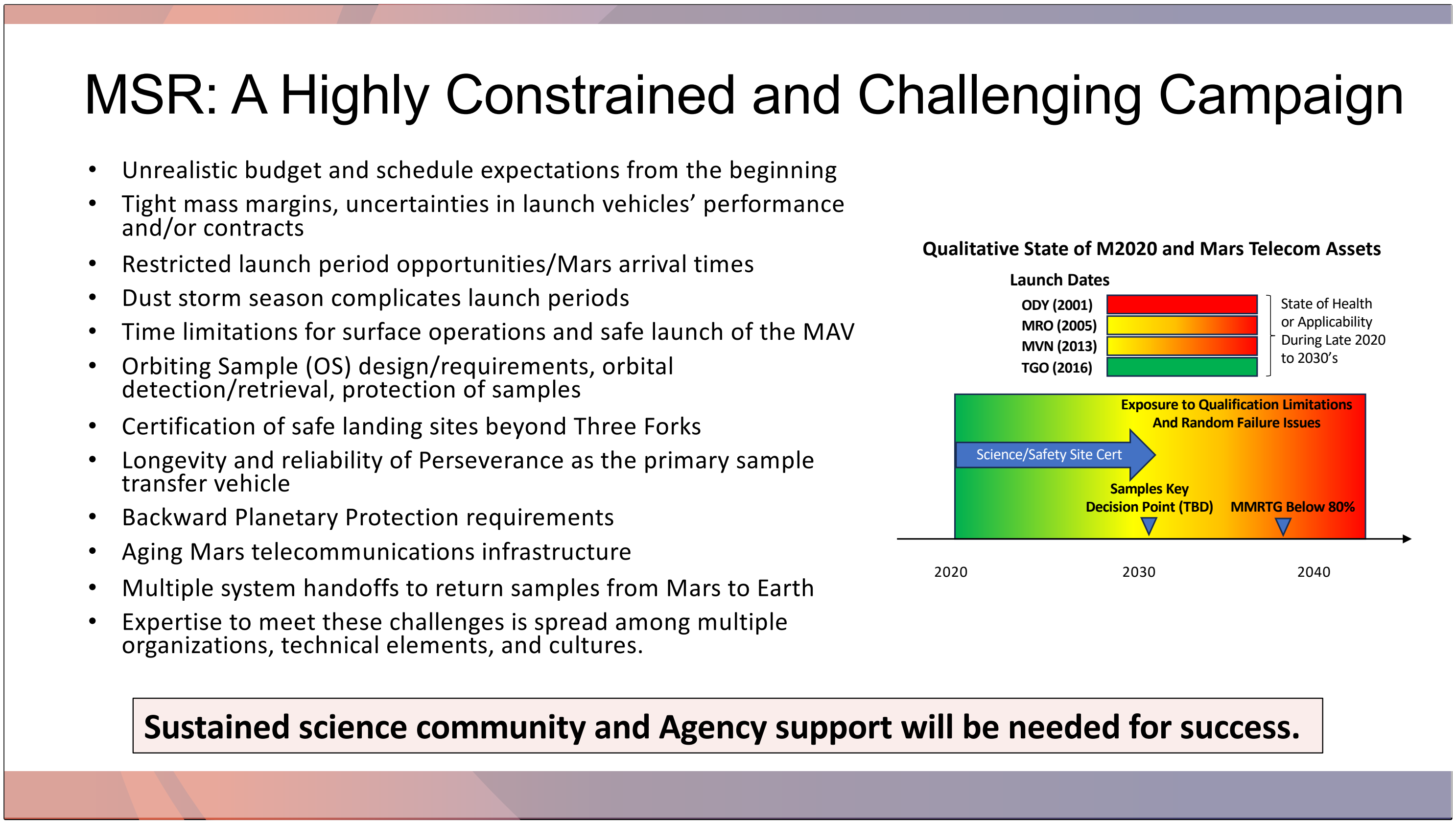
Recognition of Strengths

- Interviews with NASA and ESA personnel reflected a strong commitment to a partnership of world leadership in Mars exploration and to mission success.
- The campaign has made substantial progress since the start of formulation in 2020, despite the many external constraints and the challenging pandemic and geo-political circumstances.
- Progress and maturity from the concept reviewed by IRB-1 demonstrates an impressive level of commitment by a team with world-class talent.
- The team has recognized the challenge of a program with such diverse partners and is developing the cross-cultural understanding necessary to accomplish the program.
- The Mars 2020 science team has done an excellent job of operating the Perseverance rover as the fundamental first element of MSR.
  - An early depot of returnable samples has been placed on the crater floor at Three Forks.
  - Additional samples from the delta top have been collected by Perseverance. Samples from the margin and rim of Jezero Crater are anticipated. These samples significantly increase the scientific value above the samples at Three Forks.

Two key lessons learned from JWST and other efforts of similar magnitude point to two crucial factors for mission success:

- World class talent
- Strong systems engineering

The MSR program showed strong irrefutable evidence of both factors.



MSR: A Highly Constrained and Challenging Campaign

- Unrealistic budget and schedule expectations from the beginning
- Tight mass margins, uncertainties in launch vehicles' performance and/or contracts
- Restricted launch period opportunities/Mars arrival times
- Dust storm season complicates launch periods
- Time limitations for surface operations and safe launch of the MAV
- Orbiting Sample (OS) design/requirements, orbital detection/retrieval, protection of samples
- Certification of safe landing sites beyond Three Forks
- Longevity and reliability of Perseverance as the primary sample transfer vehicle
- Backward Planetary Protection requirements
- Aging Mars telecommunications infrastructure
- Multiple system handoffs to return samples from Mars to Earth
- Expertise to meet these challenges is spread among multiple organizations, technical elements, and cultures.

Qualitative State of M2020 and Mars Telecom Assets

Sustained science community and Agency support will be needed for success.

MSR an exceptionally challenging campaign due to the many intrinsic and extrinsic constraints that need to be simultaneously balanced for the technical and programmatic solutions to close.

The qualitative assessment related to the orbital assets and M2020 shown on the slide are consistent with NASA practice for assessment of risk:
Green (G) - Status is Satisfactory
Yellow (Y) - Status is Cautionary
Red (R) - Status is Unsatisfactory

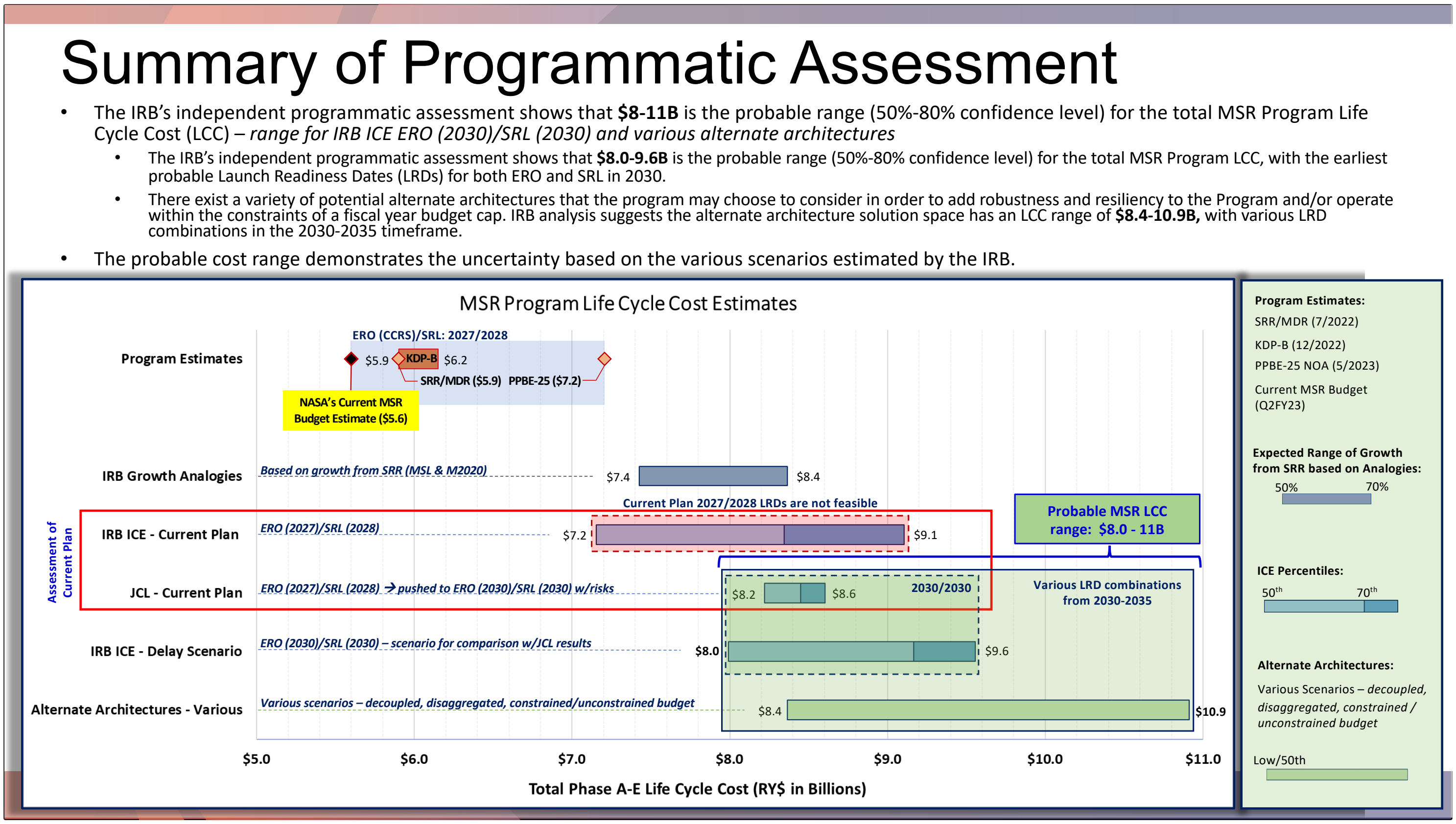
Key Takeaways From All Findings (1 of 2)

- The strategic and high scientific value of MSR is not being communicated appropriately.
- MSR is a deep-space exploration priority for NASA, in collaboration with ESA. However, MSR was established with unrealistic budget and schedule expectations from the beginning. MSR was also organized under an unwieldy structure.
- As a result, there is currently no credible, congruent technical, nor properly margined schedule, cost, and technical baseline that can be accomplished with the likely available funding.
  - Technical issues, risks, and performance-to-date indicate a near zero probability of ERO/CCRS or SRL/MAV meeting the 2027/2028 Launch Readiness Dates (LRDs). Potential LRDs exist in 2030, given adequate funding and timely resolution of issues.
  - The projected overall budget for MSR in the FY24 President's Budget Request is not adequate to accomplish the current program of record.
  - A 2030 LRD for both SRL and ERO is estimated to require ~$8.0-9.6B, with funding in excess of $1B per year to be required for three or more years starting in 2025.
- Decoupling the LRDs of SRL and ERO, as well as consideration of alternate architectures in combination with later LRDs, can yield an MSR Program that is potentially able to fit within the likely annual funding constraints.

The focus of the IRB was to explore broadly and deeply in keeping with its charter, in order to increase the probability of mission success. The IRB arrived at a total of twenty findings reflecting the areas of greatest concern. In most cases more than one finding will be traceable to the Key Takeaways. The intent of the Key Takeaways is to summarize where the biggest challenges exist for the MSR Program.

Key Takeaways From All Findings (2 of 2)

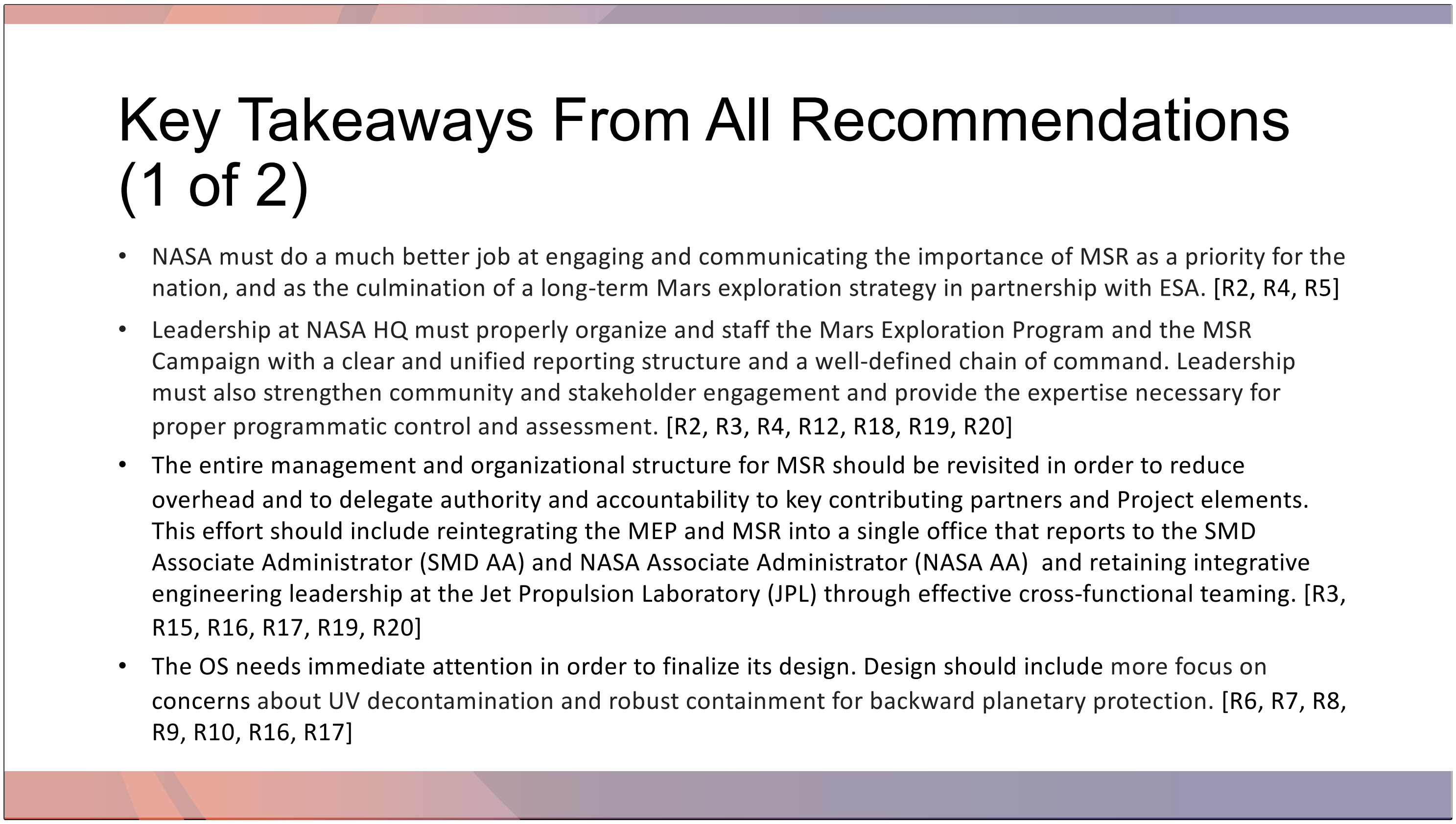
- MSR is a very complex Program and campaign with multiple parallel developments, interfaces, and complexities that are beyond the experience base of the Science Mission Directorate and the participants.
    - The organizational arrangement greatly amplifies cultural differences and dynamics.
- The MSR campaign (i.e., MEP and MSR) is not arranged to be led effectively.
- Program management is impeded by the following:
    - The structure of MSR as a hybrid Single-Program/Tightly-Coupled Program
    - Deficiencies in the organizational and programmatic oversight structure
    - Unclear roles, accountability, and authority
- Mars 2020 has been successful in acquiring samples of high scientific value, with a potentially substantial increase in science value in the samples that are yet to be collected on the crater margin and rim.
- The lack of a well-defined Orbiting Sample (OS) design continues to impact and constrain many MSR systems, with implications that affect UltraViolet (UV) decontamination and robust containment for backward planetary protection.



Summary of Programmatic Assessment

- The IRB's independent programmatic assessment shows that **$8-11B** is the probable range (50%-80% confidence level) for the total MSR Program Life Cycle Cost (LCC) – *range for IRB ICE ERO (2030)/SRL (2030) and various alternate architectures*
  - The IRB's independent programmatic assessment shows that **$8.0-9.6B** is the probable range (50%-80% confidence level) for the total MSR Program LCC, with the earliest probable Launch Readiness Dates (LRDs) for both ERO and SRL in 2030.
  - There exist a variety of potential alternate architectures that the program may choose to consider in order to add robustness and resiliency to the Program and/or operate within the constraints of a fiscal year budget cap. IRB analysis suggests the alternate architecture solution space has an LCC range of **$8.4-10.9B,** with various LRD combinations in the 2030-2035 timeframe.
- The probable cost range demonstrates the uncertainty based on the various scenarios estimated by the IRB.

The IRB performed an independent programmatic assessment of MSR's current plan that reflects the ERO/CCRS 2027 and SRL/MAV 2028 Launch Readiness Dates (LRDs). Several different methodologies were used including analogous growth factors, Independent Cost Estimating (ICE), and Joint Confidence Level (JCL) analysis. The JCL analysis indicates that the currently planned LRDs are not feasible, with the earliest probable LRDs for both ERO and SRL in 2030. The ICE for the delayed 2030/2030 LRD scenario combined with the JCL results suggest a probable $8B-9.6B lifecycle cost range. The IRB also analyzed a range of alternate architectures with varied launch scenarios to cover the potential solution space for a replanned, robust and resilient MSR program, with several options constrained to fiscal year costs of $850M to $1B. The alternate architecture analysis estimates the probable lifecycle cost range of alternative architectures to be approximately $8.4-10.9B. Overall, the IRB analysis suggests the alternate architecture solution space has an LCC range of $8.4-10.9B, with various LRD combinations in the 2030-2035 timeframe.



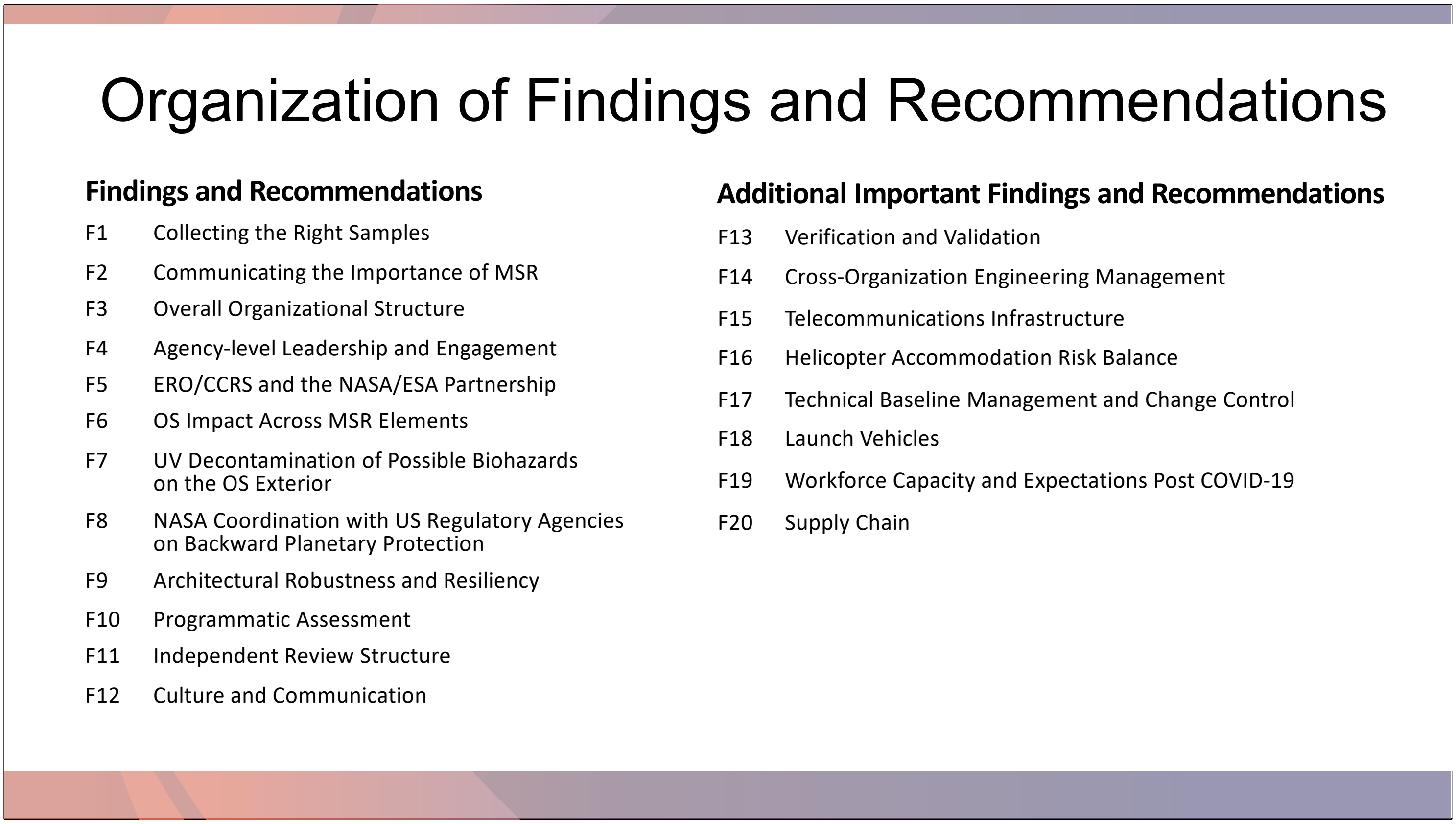
Key Takeaways From All Recommendations (1 of 2)

- NASA must do a much better job at engaging and communicating the importance of MSR as a priority for the nation, and as the culmination of a long-term Mars exploration strategy in partnership with ESA. [R2, R4, R5]
- Leadership at NASA HQ must properly organize and staff the Mars Exploration Program and the MSR Campaign with a clear and unified reporting structure and a well-defined chain of command. Leadership must also strengthen community and stakeholder engagement and provide the expertise necessary for proper programmatic control and assessment. [R2, R3, R4, R12, R18, R19, R20]
- The entire management and organizational structure for MSR should be revisited in order to reduce overhead and to delegate authority and accountability to key contributing partners and Project elements. This effort should include reintegrating the MEP and MSR into a single office that reports to the SMD Associate Administrator (SMD AA) and NASA Associate Administrator (NASA AA) and retaining integrative engineering leadership at the Jet Propulsion Laboratory (JPL) through effective cross-functional teaming. [R3, R15, R16, R17, R19, R20]
- The OS needs immediate attention in order to finalize its design. Design should include more focus on concerns about UV decontamination and robust containment for backward planetary protection. [R6, R7, R8, R9, R10, R16, R17]

In most cases, more than one finding will be traceable to the Key Takeaways in a similar fashion to the Key Takeaways from All Findings.

Key Takeaways From All Recommendations (2 of 2)

- The most important sample science may lie ahead on the crater rim, and this material should be included in the returned sample set. [R1]
- NASA should establish MSR as a Tightly-Coupled Program with separate Standing Review Boards (SRBs) for SRL, MAV, and CCRS. This approach should include in-depth programmatic assessment (including JCLs) to be reconciled at the Program level by an SRB similarly to what the IRB did. [R3, R4, R9, R10, R11]
- NASA and ESA should collaborate more closely in order to better integrate the ERO spacecraft and CCRS teams into a one-team approach wherein ESA plays a larger role in order to provide greater programmatic resilience to the overall campaign. [R3, R5, R6, R7, R8, R9, R10]
- Alternate architectures should be examined under clear guidelines provided by NASA HQ for yearly budget constraints, while acknowledging that the lifecycle cost will likely be in the $8 to $11B range regardless of architectural choices. [R9, R10, R13, R14]
- NASA should not baseline the MSR campaign until credible congruent technical and programmatic plans are developed with demonstration of proper technical margins, robustness, and resilience. These values should be consistent with plans for an annual budget that ensures mission success. [R1 to R20]



Organization of Findings and Recommendations

Findings and Recommendations

F1 Collecting the Right Samples
F2 Communicating the Importance of MSR
F3 Overall Organizational Structure
F4 Agency-level Leadership and Engagement
F5 ERO/CCRS and the NASA/ESA Partnership
F6 OS Impact Across MSR Elements
F7 UV Decontamination of Possible Biohazards on the OS Exterior
F8 NASA Coordination with US Regulatory Agencies on Backward Planetary Protection
F9 Architectural Robustness and Resiliency
F10 Programmatic Assessment
F11 Independent Review Structure
F12 Culture and Communication

Additional Important Findings and Recommendations

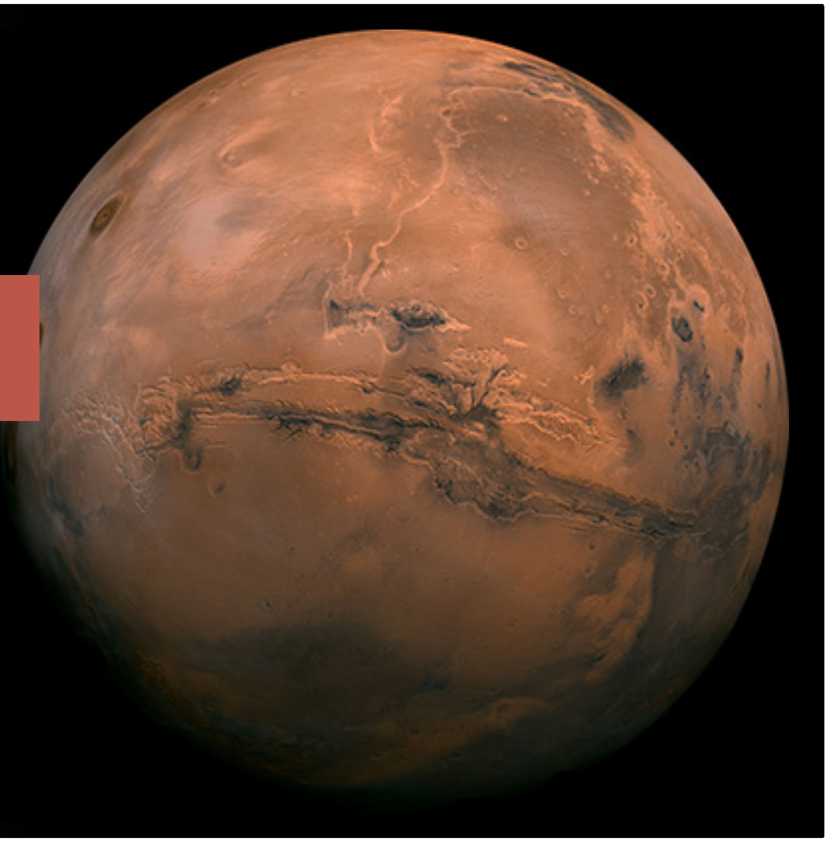
F13 Verification and Validation
F14 Cross-Organization Engineering Management
F15 Telecommunications Infrastructure
F16 Helicopter Accommodation Risk Balance
F17 Technical Baseline Management and Change Control
F18 Launch Vehicles
F19 Workforce Capacity and Expectations Post COVID-19
F20 Supply Chain

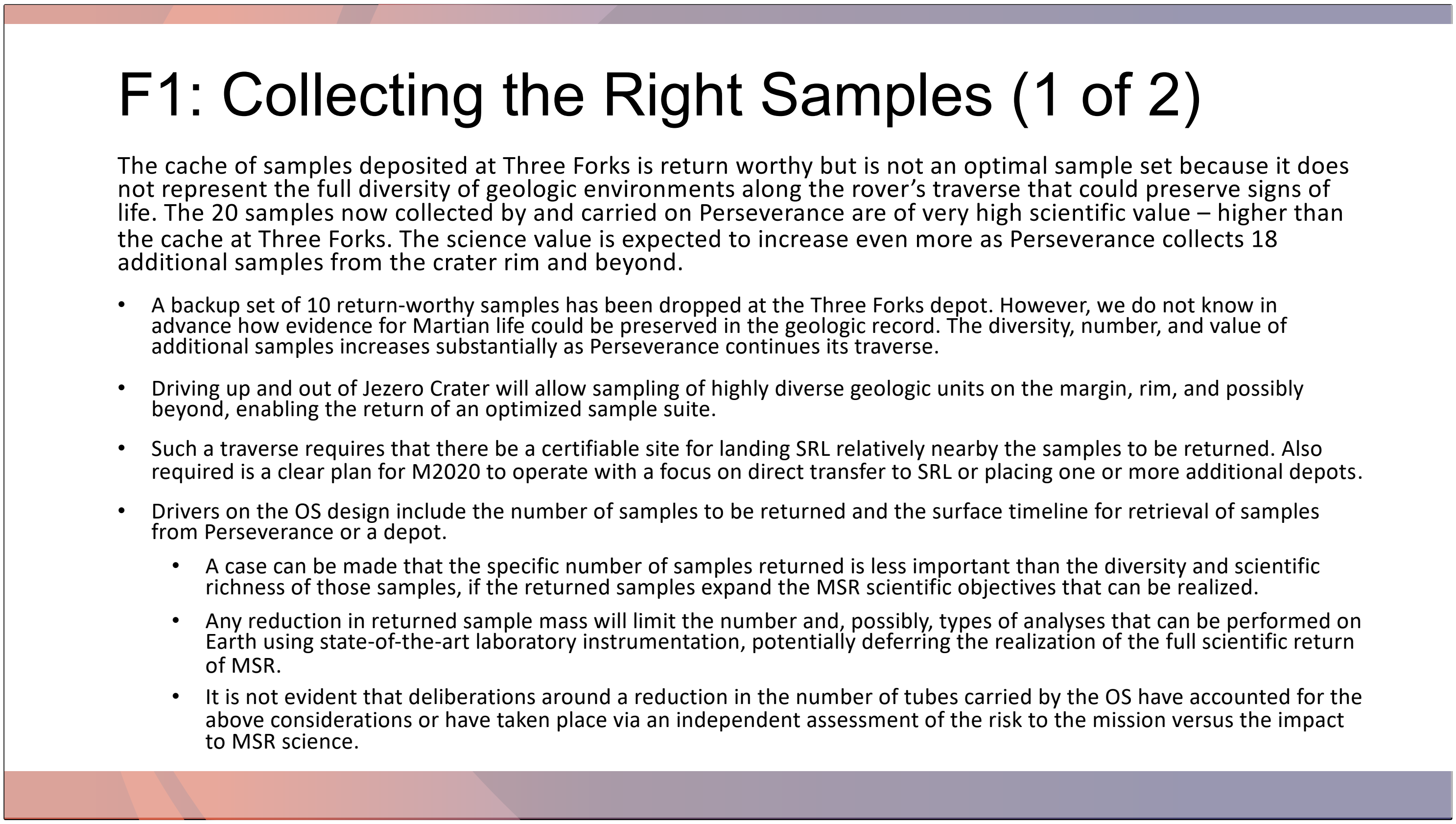
The slight distinction between “Findings and Recommendations” versus “Additional Important Findings and Recommendations” is as follows:

- Findings and Recommendations are those entries with broad, all-encompassing implications to the MSR Campaign and inter-Center/Inter Agency agreements.

- Additional Important Findings and Recommendations are those entries with system-level design or execution implications. These entries includes findings such as Verification and Validation, Launch Vehicles, Workforce Capacity and Expectations post COVID, and Supply Chain.

Findings and Recommendations





F1: Collecting the Right Samples (1 of 2)

The cache of samples deposited at Three Forks is return worthy but is not an optimal sample set because it does not represent the full diversity of geologic environments along the rover's traverse that could preserve signs of life. The 20 samples now collected by and carried on Perseverance are of very high scientific value – higher than the cache at Three Forks. The science value is expected to increase even more as Perseverance collects 18 additional samples from the crater rim and beyond.

- A backup set of 10 return-worthy samples has been dropped at the Three Forks depot. However, we do not know in advance how evidence for Martian life could be preserved in the geologic record. The diversity, number, and value of additional samples increases substantially as Perseverance continues its traverse.
- Driving up and out of Jezero Crater will allow sampling of highly diverse geologic units on the margin, rim, and possibly beyond, enabling the return of an optimized sample suite.
- Such a traverse requires that there be a certifiable site for landing SRL relatively nearby the samples to be returned. Also required is a clear plan for M2020 to operate with a focus on direct transfer to SRL or placing one or more additional depots.
- Drivers on the OS design include the number of samples to be returned and the surface timeline for retrieval of samples from Perseverance or a depot.
  - A case can be made that the specific number of samples returned is less important than the diversity and scientific richness of those samples, if the returned samples expand the MSR scientific objectives that can be realized.
  - Any reduction in returned sample mass will limit the number and, possibly, types of analyses that can be performed on Earth using state-of-the-art laboratory instrumentation, potentially deferring the realization of the full scientific return of MSR.
  - It is not evident that deliberations around a reduction in the number of tubes carried by the OS have accounted for the above considerations or have taken place via an independent assessment of the risk to the mission versus the impact to MSR science.

A carefully considered, science-based rationale for the return of 500 g (~1.1 pound) of Martian sample material has been documented in the peer-reviewed scientific literature several times over more than a decade. The scientific justification for returning 500 g of Martian sample material is based in part on in the types of expected analyses and the quantities of sample material needed to conduct these analyses. The sample tubes are estimated to hold at the most 15-16 g each. This design results in the planned capacity of the OS to return ~32 tubes. Not all of the tubes will be filled to capacity, and only a portion of the returned material will be made available to researchers in the years immediately following the tubes' arrival on Earth. A yet-to-be-determined quantity of the returned samples will be placed in long-term storage for future generations, as was done for Apollo lunar samples and will be done for the asteroid sample planned for return by OSIRIS-REx.

Perseverance's cache is the primary cache for return to Earth, representing the broadest diversity of samples and geological diversity of Mars. It is therefore important to strike the right balance between the largest number and the diversity of samples as the OS design is settled.

A reduction in the capacity of the OS to only 18 tubes could yield approximately 288 g (~0.64 pounds) of the desired 500 g. Given that some of this mass will go into long-term storage for future generations, even less than ~288 g would be available initially for analysis at US institutions and across the international scientific community.

R1: Collecting the Right Samples (2 of 2)

Recommendations:

- (R1.1) The relative science merit of the 10 samples on the ground at Three Forks should be independently evaluated against additional samples currently on Perseverance and samples that may be collected during continued science operation of the Perseverance rover. Science merit should be a key input to landing site selection for MSR and operational strategies for the Perseverance rover, Sample Retriever Lander (SRL), and Mars Ascent Vehicle (MAV).
- (R1.2) NASA should develop and implement a formal, metrics-based and timeline-based plan for operating Mars 2020 with a focus on direct transfer to the SRL or placing one or more additional depots.
  - Whether Perseverance 1) remains at the second certified landing site, 2) conducts sorties from that site, or 3) drops a second cache and is permitted to continue along its traverse towards a third certifiable landing site should depend on factors including the science value of the samples collected to date, the health of the rover, the mission architecture, and arrival dates of future flight elements.
- (R1.3) NASA should direct Mars 2020 to certify a landing site outside Jezero Crater as soon as feasible.
- (R1.4) Mars 2020 and MSR should develop a joint plan that balances the risk of degradation or failure of Perseverance against obtaining the highest value samples near the crater rim and beyond. The plan should be appended to the existing memorandum of agreement between MEP and MSR.
- (R1.5) NASA should revise the MSR Program requirement (6.1.1) related to the capability to return 30 sample tube assemblies and implement a requirement that is based on science value, the MSR timetable, and other factors relevant to successfully achieving the optimum science from MSR, including total sample mass.

F2 and R2: Communicating the Importance of MSR

The societal, technological, and scientific significance of MSR makes it a mission of the highest importance in NASA's long-term exploration strategy, and this is not being communicated consistently and clearly with the public and stakeholders .

- A successful MSR campaign will revolutionize our understanding of the history of Mars, the Solar System, and the potential for life beyond Earth.
- The exploration of Mars and the return of samples are integral parts of NASA's Moon-to-Mars initiative and our commitment to US space leadership in partnership with ESA.
- The technical challenge and audacity of MSR will inspire the next generation.
- NASA is not sending a consistent and unified message to Congress, the scientific community, and to the public regarding MSR's scientific and strategic importance to the nation.

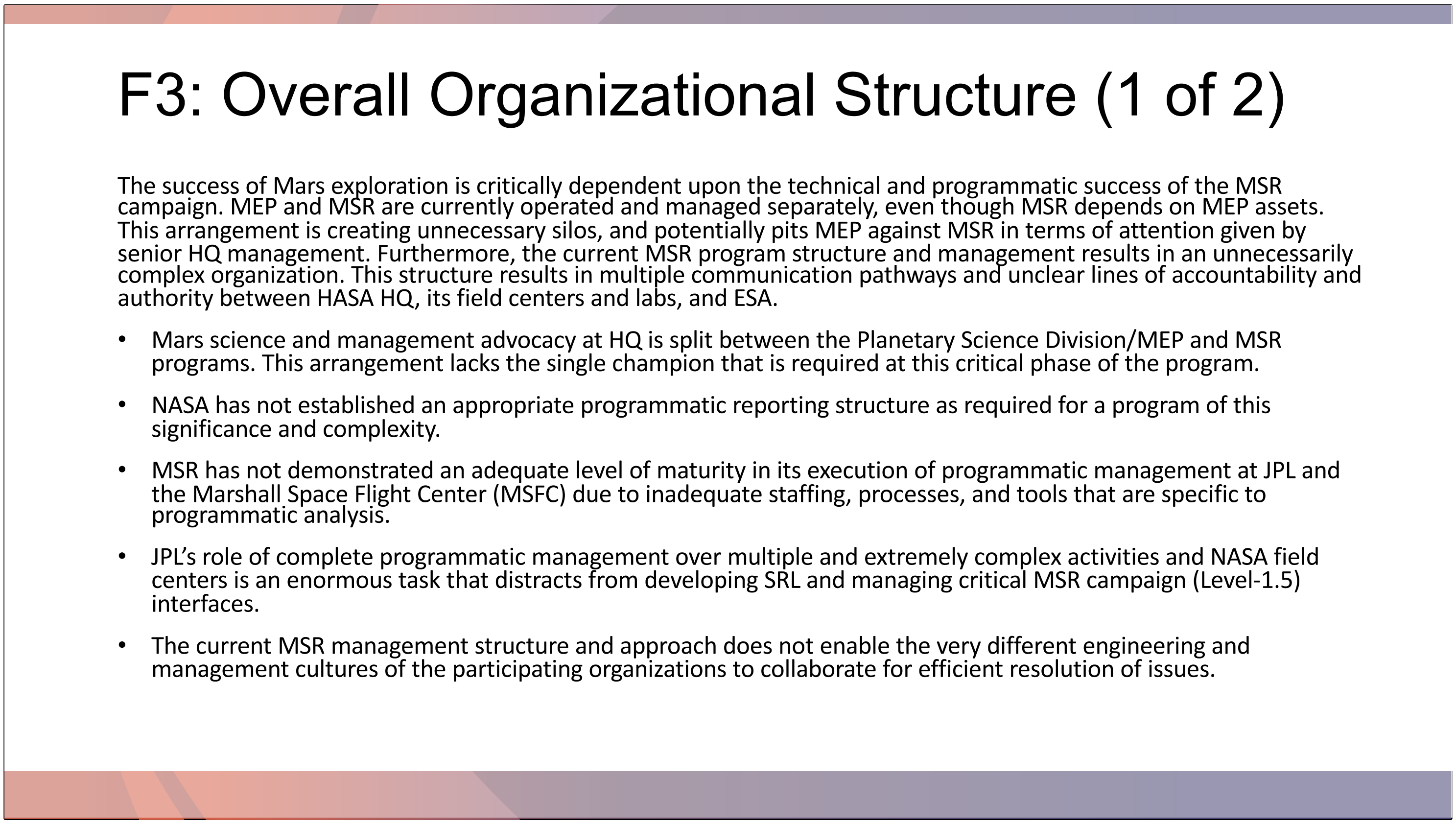
Recommendation:

- (R2.1) NASA should develop a strategy and implement a compelling communication plan that reflects MSR as an Agency priority and as a priority for the nation that historically has dared to do the seeming impossible in space. NASA's senior leadership should vigorously participate in the execution of that plan.

The planetary science community is substantially larger and more diverse now than when MSR was first conceived decades ago. We have made many new discoveries throughout the Solar System in those intervening years. The number of high-priority scientific targets of exploration has justifiably expanded, particularly since the inception of the Decadal Surveys.

However, the growth and ambition of planetary science does not change the fact that MSR remains a longstanding, two-time Decadal priority for legitimate scientific, technological, and geopolitical reasons. Now that this mission has begun with the collection of scientifically selected samples, and NASA/ESA are on the verge of being able to return those samples, **it is important to establish deeper, meaningful communication about the scientific value of this longstanding goal as well as the ways in which it will benefit NASA beyond planetary science and as part of NASA's Moon-to-Mars strategy.** A particular and understandable concern from the community is the impact that MSR may have on the rest of the Planetary Science Division and SMD flight mission portfolio. NASA must address this concern while clarifying and dispelling the notion that cancelling MSR necessarily means greater budgets for everybody else in the Planetary Science Division or even the Mars Exploration Program. Cancellation may also call into question the feasibility of other ambitious sample return efforts envisioned by the planetary science community.

It is worth adding that leadership in space exploration is a hallmark of USA's soft power in the world. Peaceful exploration of space serves to demonstrate United States' technological expertise to deliver, no matter how difficult. These efforts inspire the nation and the world community in the journey, opening the door to significant international collaborations in space. Communicating the importance of MSR as a priority for US scientific and technological reasons is important, particularly in light of China's plans for preeminence in the world stage.



F3: Overall Organizational Structure (1 of 2)

The success of Mars exploration is critically dependent upon the technical and programmatic success of the MSR campaign. MEP and MSR are currently operated and managed separately, even though MSR depends on MEP assets. This arrangement is creating unnecessary silos, and potentially pits MEP against MSR in terms of attention given by senior HQ management. Furthermore, the current MSR program structure and management results in an unnecessarily complex organization. This structure results in multiple communication pathways and unclear lines of accountability and authority between HASA HQ, its field centers and labs, and ESA.

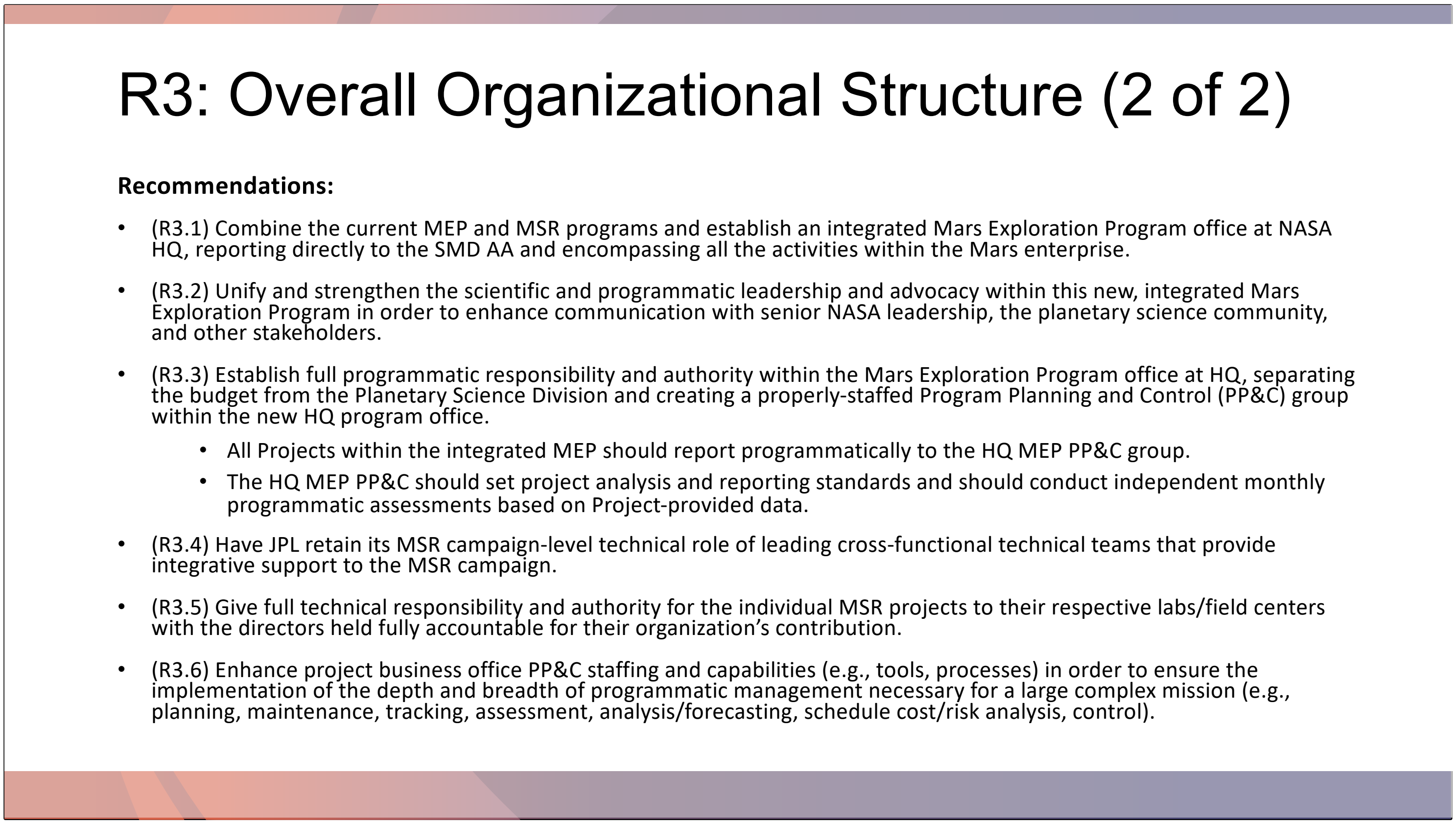
- Mars science and management advocacy at HQ is split between the Planetary Science Division/MEP and MSR programs. This arrangement lacks the single champion that is required at this critical phase of the program.
- NASA has not established an appropriate programmatic reporting structure as required for a program of this significance and complexity.
- MSR has not demonstrated an adequate level of maturity in its execution of programmatic management at JPL and the Marshall Space Flight Center (MSFC) due to inadequate staffing, processes, and tools that are specific to programmatic analysis.
- JPL's role of complete programmatic management over multiple and extremely complex activities and NASA field centers is an enormous task that distracts from developing SRL and managing critical MSR campaign (Level-1.5) interfaces.
- The current MSR management structure and approach does not enable the very different engineering and management cultures of the participating organizations to collaborate for efficient resolution of issues.

The current programmatic workforce at NASA HQ consists of a senior civil servant Deputy Program Director and one support contractor.

The MSR HQ office has provided guidance to the JPL MSR Program office regarding programmatic analysis and reporting and is being reflected in including the draft program and business plans. However, much work remains to implement these plans consistently with standards that are commensurate with a flagship mission.

The need for experienced programmatic staff increases and acquisition of assessment tools for MSR has been acknowledged by the respective institutions that are contributing to MSR.

The cultures at JPL, MSFC, GSFC, and ESA differ in multiple ways, particularly in the degree of structure in their decision, documentation, and Project control processes. A key part of NASA HQ's Program Office role is to be able to normalize the inputs and metrics against plans.



R3: Overall Organizational Structure (2 of 2)

Recommendations:

- (R3.1) Combine the current MEP and MSR programs and establish an integrated Mars Exploration Program office at NASA HQ, reporting directly to the SMD AA and encompassing all the activities within the Mars enterprise.
- (R3.2) Unify and strengthen the scientific and programmatic leadership and advocacy within this new, integrated Mars Exploration Program in order to enhance communication with senior NASA leadership, the planetary science community, and other stakeholders.
- (R3.3) Establish full programmatic responsibility and authority within the Mars Exploration Program office at HQ, separating the budget from the Planetary Science Division and creating a properly-staffed Program Planning and Control (PP&C) group within the new HQ program office.
  - All Projects within the integrated MEP should report programmatically to the HQ MEP PP&C group.
  - The HQ MEP PP&C should set project analysis and reporting standards and should conduct independent monthly programmatic assessments based on Project-provided data.
- (R3.4) Have JPL retain its MSR campaign-level technical role of leading cross-functional technical teams that provide integrative support to the MSR campaign.
- (R3.5) Give full technical responsibility and authority for the individual MSR projects to their respective labs/field centers with the directors held fully accountable for their organization’s contribution.
- (R3.6) Enhance project business office PP&C staffing and capabilities (e.g., tools, processes) in order to ensure the implementation of the depth and breadth of programmatic management necessary for a large complex mission (e.g., planning, maintenance, tracking, assessment, analysis/forecasting, schedule cost/risk analysis, control).

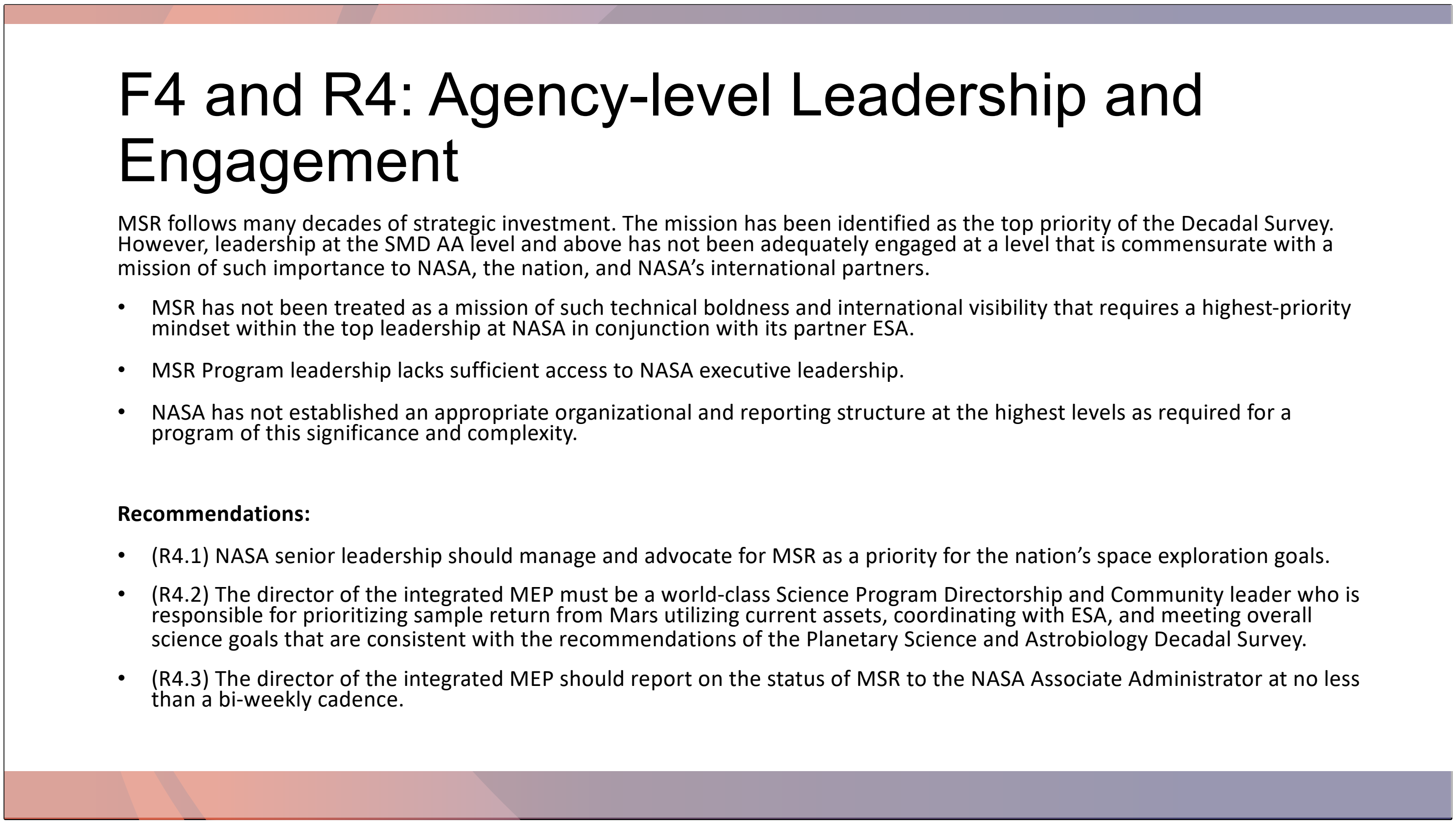
NASA would need to augment the integrated MEP programmatic staff above the combined levels in the current MSR and MEP in order to ensure that there is sufficient program planning and control (e.g., cost and schedule planning, maintenance, tracking, assessment, analysis, forecasting and risk analysis).

To enable SRL and MAV to analyze and report cost and schedule status effectively, both of their programmatic teams will need to be augmented with 3-4 highly qualified FTE/WYEs.

The JPL campaign-level technical role includes providing key technical support to the MEP office at HQ.

Definition of full responsibility for the individual MSR Projects entails the following:

- JPL retains full responsibility and authority for SRL.
- Goddard Space Flight Center assumes full responsibility and authority for the CCRS payload contribution to the ESA-provided ERO mission, along with authority for JPL-provided hardware.
- Marshall Space Flight Center assumes full responsibility and authority for the MAV payload contribution to the JPL-provided SRL.
- Push responsibility for programmatic controls to the particular MSR project.



F4 and R4: Agency-level Leadership and Engagement

MSR follows many decades of strategic investment. The mission has been identified as the top priority of the Decadal Survey. However, leadership at the SMD AA level and above has not been adequately engaged at a level that is commensurate with a mission of such importance to NASA, the nation, and NASA's international partners.

- MSR has not been treated as a mission of such technical boldness and international visibility that requires a highest-priority mindset within the top leadership at NASA in conjunction with its partner ESA.
- MSR Program leadership lacks sufficient access to NASA executive leadership.
- NASA has not established an appropriate organizational and reporting structure at the highest levels as required for a program of this significance and complexity.

Recommendations:

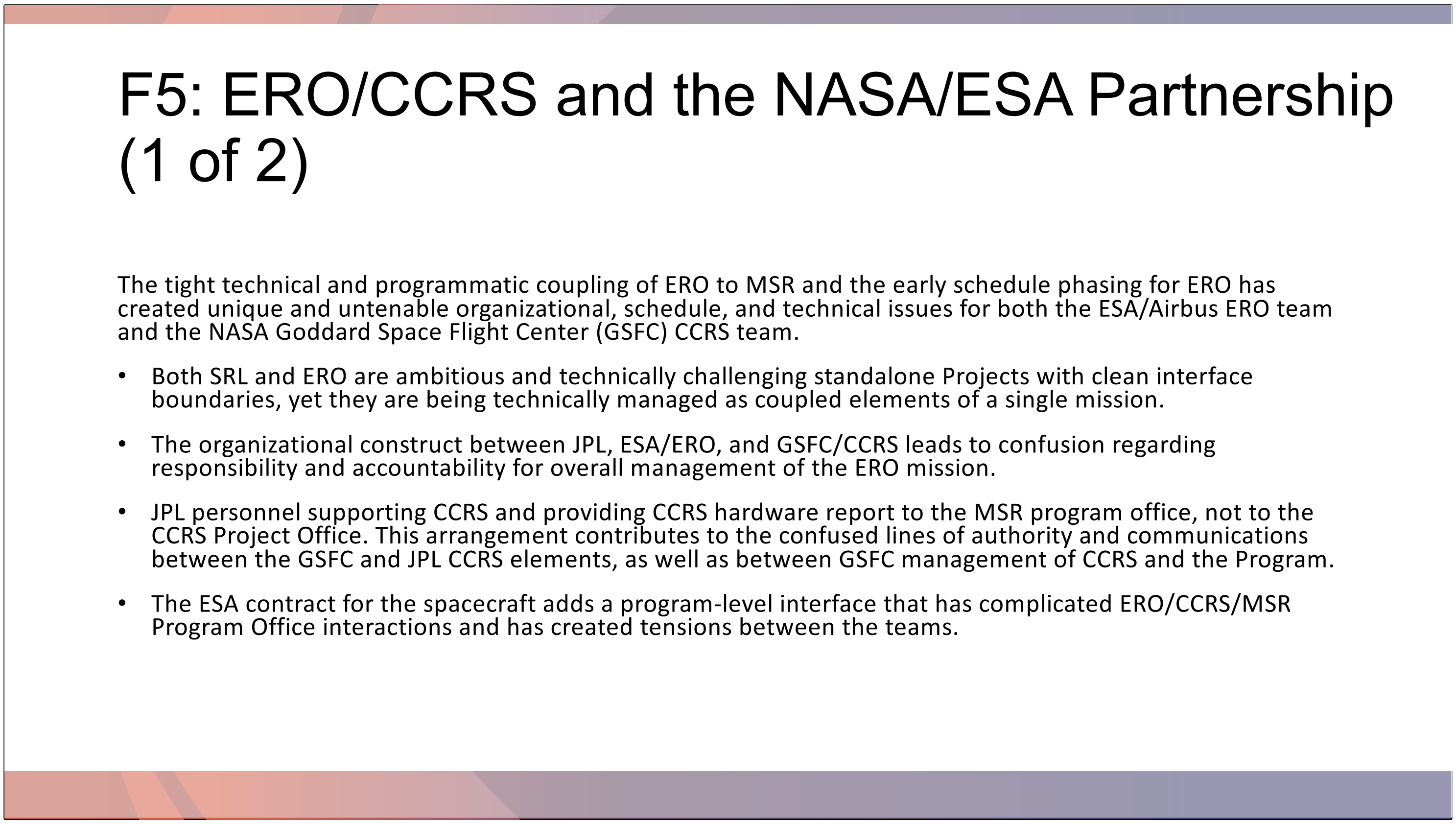
- (R4.1) NASA senior leadership should manage and advocate for MSR as a priority for the nation's space exploration goals.
- (R4.2) The director of the integrated MEP must be a world-class Science Program Directorship and Community leader who is responsible for prioritizing sample return from Mars utilizing current assets, coordinating with ESA, and meeting overall science goals that are consistent with the recommendations of the Planetary Science and Astrobiology Decadal Survey.
- (R4.3) The director of the integrated MEP should report on the status of MSR to the NASA Associate Administrator at no less than a bi-weekly cadence.

MSR represents a greater than ~$20 billion investment to date and a very challenging mission in the $8-11B class. All the components must work with narrow margins for error. The end-to-end effort requires a heightened level of attention, risk management, and reassurances.

Programs of this magnitude and complexity, particularly those with multiple centers and international partnerships (e.g., ISS, JWST, Shuttle, Hubble, Artemis) have historically had direct and regular access, interaction, and accountability with the HQ A-suite. Each of these programs have had very challenging phases where top-level attention and actions were key to their success.

This finding also relates to agency-level proactive advocacy in terms of public interactions (speeches, social media, outreach events, conferences) and congressional interactions (testimony, Hill visits, talking points, industry alignment). These same programs have also faced difficult gauntlets in terms of public and administration/congressional support. During these challenging times, advocacy made the difference between success and failure.

MEP deserves world-class leadership with proven records of success. Strong leadership is required to:
- Create a team culture that is aligned around the mission objectives and mission success
- Communicating strategy and vision, keeping stakeholders onboard
- Keep all of the partners and projects aligned
- Making and communicating well-considered, integrated, and sometimes difficult decisions



F5: ERO/CCRS and the NASA/ESA Partnership (1 of 2)

The tight technical and programmatic coupling of ERO to MSR and the early schedule phasing for ERO has created unique and untenable organizational, schedule, and technical issues for both the ESA/Airbus ERO team and the NASA Goddard Space Flight Center (GSFC) CCRS team.

- Both SRL and ERO are ambitious and technically challenging standalone Projects with clean interface boundaries, yet they are being technically managed as coupled elements of a single mission.
- The organizational construct between JPL, ESA/ERO, and GSFC/CCRS leads to confusion regarding responsibility and accountability for overall management of the ERO mission.
- JPL personnel supporting CCRS and providing CCRS hardware report to the MSR program office, not to the CCRS Project Office. This arrangement contributes to the confused lines of authority and communications between the GSFC and JPL CCRS elements, as well as between GSFC management of CCRS and the Program.
- The ESA contract for the spacecraft adds a program-level interface that has complicated ERO/CCRS/MSR Program Office interactions and has created tensions between the teams.

The MSR campaign architecture requires tight operational, scheduling, and design coordination between JPL, Goddard, ESA, and ESA’s spacecraft vendor Airbus. This arrangement introduces notable communication and coordination challenges, especially when addressing the intricate engineering issues tied to the ERO mission. ERO’s design is highly impacted by the MSR campaign design, which subsequently affects the CCRS design. CCRS has significant componentry provided by JPL, which is also in charge of the overall campaign design. These dynamics create circular interconnected dependencies on top of difficult engineering challenges.

The timing of ERO's Mars orbit arrival to support SRL’s EDL and surface operations results in an intricately linked development and launch schedule dependency between ERO and SRL. This dependency influences costs and introduces complexities into engineering design decisions. When evaluating the primary objectives of each mission, there are opportunities to streamline these interactions at the highest level, particularly in relation to the recovery of the OS in Mars orbit. This recovery could occur at an unspecified time, obviating the necessity for a specific order and timing of SRL and ERO launches.

The fixed-price and contract management approach with Airbus requires ESA to be understandably guarded regarding interactions between CCRS and Airbus engineering. With the spacecraft bus design well ahead of CCRS, the GSFC team has had to design CCRS to accommodate the spacecraft bus and a highly prescribed set of interfaces. The complexity is further compounded by uncertainty regarding the choice of the launch vehicle for ERO. Interactions and technical interchange between ESA, CCRS, and Airbus have not been adequate given the complex nature of the ERO mission.

R5: ERO/CCRS and the NASA/ESA Partnership (2 of 2)

Recommendation:

- (R5.1) Decouple the ERO and SRL development schedules by transferring full responsibility for the integrated ERO mission to ESA. This arrangement will allow GSFC to work with ESA and Airbus without going through JPL.
  - Focus the NASA/JPL efforts on the elements and infrastructure that are required to get the OS into a defined and stable Mars orbit through all available assets (in collaboration with ESA for Trace Gas Orbiter (TGO) relay communications), while ESA focuses on OS retrieval and OS return to Earth.
  - JPL should continue to lead overall campaign technical integration and management of Level 1.5 requirements including backward planetary protection, in proper coordination with ESA.
  - Accept ESA's ability to successfully accomplish ERO, recognizing ERO's importance to ESA and its goals in Mars exploration.
  - Give GSFC full responsibility and authority for leading the CCRS development (including the JPL components) as a deliverable payload to ESA.
    - ESA should provide adequate visibility into driving technical parameters and margins and should help facilitate closure of the CCRS design.
    - NASA and ESA should collaborate more closely in order to better integrate the ERO spacecraft and CCRS teams into a one-team approach that incorporates contractual considerations into a modified interagency agreement.

The MSR campaign should be approached as two distinct missions. Both missions rank among the most challenging endeavors ever undertaken by NASA and its partner ESA. SRL's mission involves recovering samples from Perseverance and placing them into a well-defined and stable Mars orbit. ERO retrieves these samples from Mars orbit and returns them to Earth. Consequently, the primary interplay between the two missions revolves around the OS design, encompassing considerations such as mass, volume, shape, Mars orbit, and reverse planetary protection for all phases of the MSR campaign. By centering the interaction between the two missions on OS recovery and planetary protection, each organization can devote its resources entirely to its MSR campaign contribution and can assume complete accountability for its success.

Given the intricacies of both the ERO spacecraft and CCRS, coupled with the separation of the ERO and CCRS missions, it becomes imperative for NASA and ESA to closely align their Airbus and CCRS teams. This alignment is crucial to provide each team with essential insights into the other's designs, allow collaborative solutions to each other's issues, and to establish a unified approach to agreed-upon verification methods.

F6 and R6: OS Impact Across MSR Elements

The OS is the critical element that is central to the entire MSR mission. Failure to converge upon an acceptable and stable OS design will continue to produce significant design uncertainty throughout the elements of any MSR Program architecture.

- The OS problem is uniquely complex because the OS is not only highly constrained due to mission requirements, but the OS also touches multiple systems in every MSR project element.
- Finalizing the OS design is critical to establishing a technical and programmatic baseline, as well as for helping settle backward planetary protection issues.
- Key partners at NASA Centers and ESA report cost impacts, schedule delays, and the stress of personnel that are caused by repeated redesign of OS accommodations and interfaces.

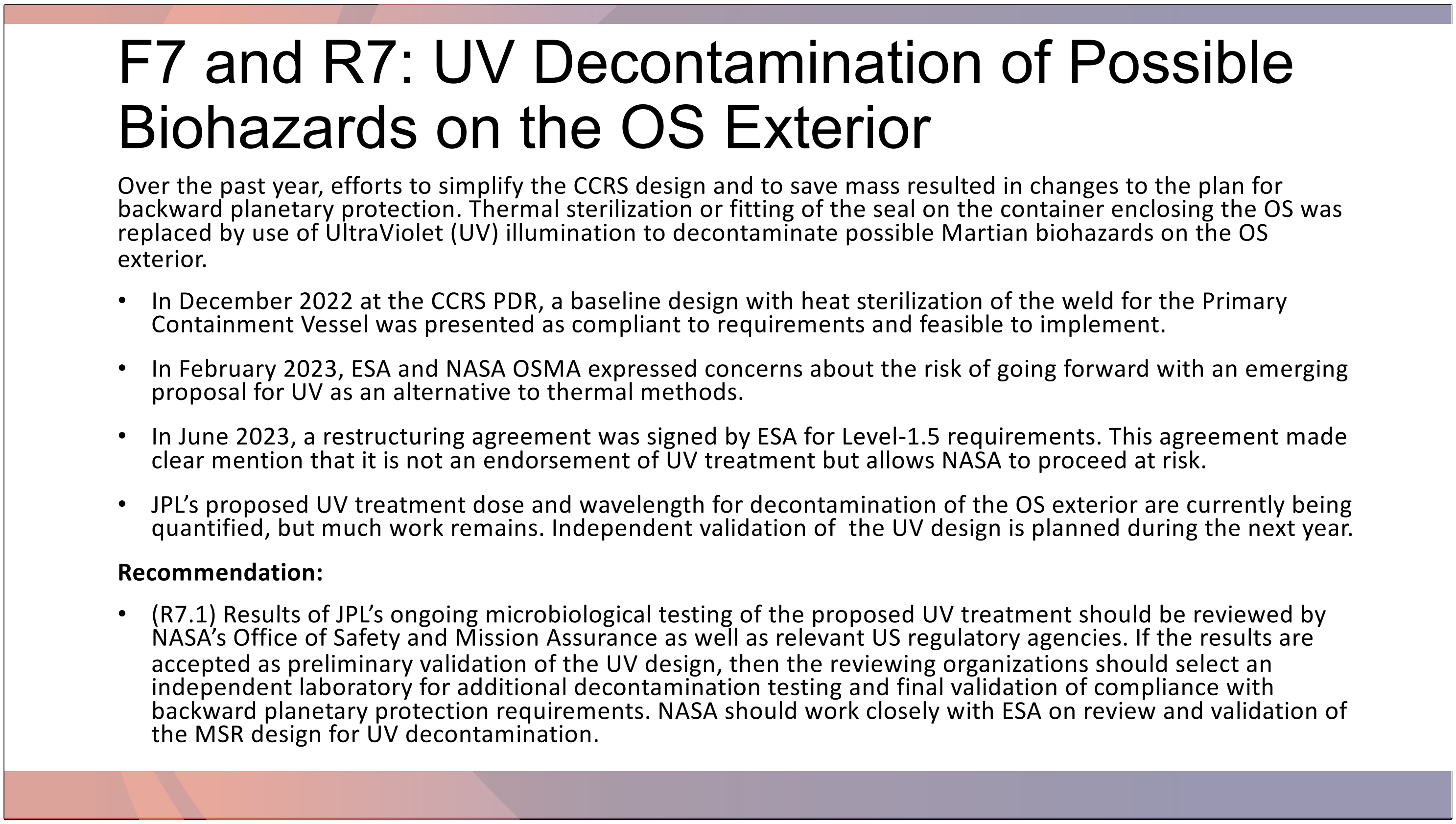
Recommendation:

- (R6.1) Close the OS design and all associated interfaces before the Program's preliminary design review season. Even if there are changes in the overall MSR Program plans, and these changes cause changes in the OS, the necessity of closing the OS design as soon as possible (and before other elements' designs are finalized and reviewed) remains undiminished.

The OS is a critical element of any Mars Sample Return architecture, serving as the primary containment vessel for the samples and their launch into Mars orbit. The OS must be discoverable in Mars orbit for an extended period, captured, contained, decontaminated, and secured into the Earth return vehicle for landing after the return journey to Earth.

Various systems and organizations interface through the OS. OS design interfaces with, and thus is constrained by and impacts, all parts of the MSR system.

- The OS is implemented by the Jet Propulsion Laboratory.
- The mass and volume of the OS is driven by the number of sample tubes it needs to contain, sample integrity and planetary protection requirements, as well as robotic manipulation related interfaces with the Sample Transfer Arm (STA, supplied by the European Space Agency)
- In turn, the mass and volume of the OS drives the size of the Mars Ascent Vehicle (MAV; managed by Marshall Spaceflight Center). MAV in turns drives the size and mass of the Sample Return Lander (SRL; managed by the Jet Propulsion Laboratory) and its launch vehicle.
- The exterior optical properties of the OS are critical for detectability by the Earth Return Orbiter (ERO; supplied by the European Space Agency).
- The OS also drives the Capture Containment and Return System in several ways (CCRS; managed by Goddard Space Flight Center with some elements contributed by the Jet Propulsion Laboratory). The CCRS is accommodated on the ERO.



F7 and R7: UV Decontamination of Possible Biohazards on the OS Exterior

Over the past year, efforts to simplify the CCRS design and to save mass resulted in changes to the plan for backward planetary protection. Thermal sterilization or fitting of the seal on the container enclosing the OS was replaced by use of UltraViolet (UV) illumination to decontaminate possible Martian biohazards on the OS exterior.

- In December 2022 at the CCRS PDR, a baseline design with heat sterilization of the weld for the Primary Containment Vessel was presented as compliant to requirements and feasible to implement.
- In February 2023, ESA and NASA OSMA expressed concerns about the risk of going forward with an emerging proposal for UV as an alternative to thermal methods.
- In June 2023, a restructuring agreement was signed by ESA for Level-1.5 requirements. This agreement made clear mention that it is not an endorsement of UV treatment but allows NASA to proceed at risk.
- JPL's proposed UV treatment dose and wavelength for decontamination of the OS exterior are currently being quantified, but much work remains. Independent validation of the UV design is planned during the next year.

Recommendation:

- (R7.1) Results of JPL's ongoing microbiological testing of the proposed UV treatment should be reviewed by NASA's Office of Safety and Mission Assurance as well as relevant US regulatory agencies. If the results are accepted as preliminary validation of the UV design, then the reviewing organizations should select an independent laboratory for additional decontamination testing and final validation of compliance with backward planetary protection requirements. NASA should work closely with ESA on review and validation of the MSR design for UV decontamination.

At the CCRS PDR in December 2022, thermal welding to close and sterilize the seal on a container enclosing the OS was presented as meeting success criteria. The IRB did not hear a compelling explanation for why subsequent to PDR, the thermal plan was deemed too complex and was replaced with a plan for UV treatment. Being new, the UV treatment plan requires extensive testing of effective biological kill and the flight readiness of the UV source.

F8: NASA Coordination with US Regulatory Agencies on Backward Planetary Protection (1 of 2)

The Office of the Chief Scientist (OCS) coordinated an Independent Scientific Review of the potential use of an active UltraViolet (UV) treatment to minimize or eliminate possible Martian biohazard contamination on the exterior of the OS. This study was an important step toward interagency coordination on MSR. The review recommendations include substantial additional work to confirm dust-load models, to evaluate the effectiveness of UV for microbiological and macromolecular decontamination, and to develop a mechanism for verification that the UV illumination system will operate as planned during capture and containment of the OS in orbit at Mars.

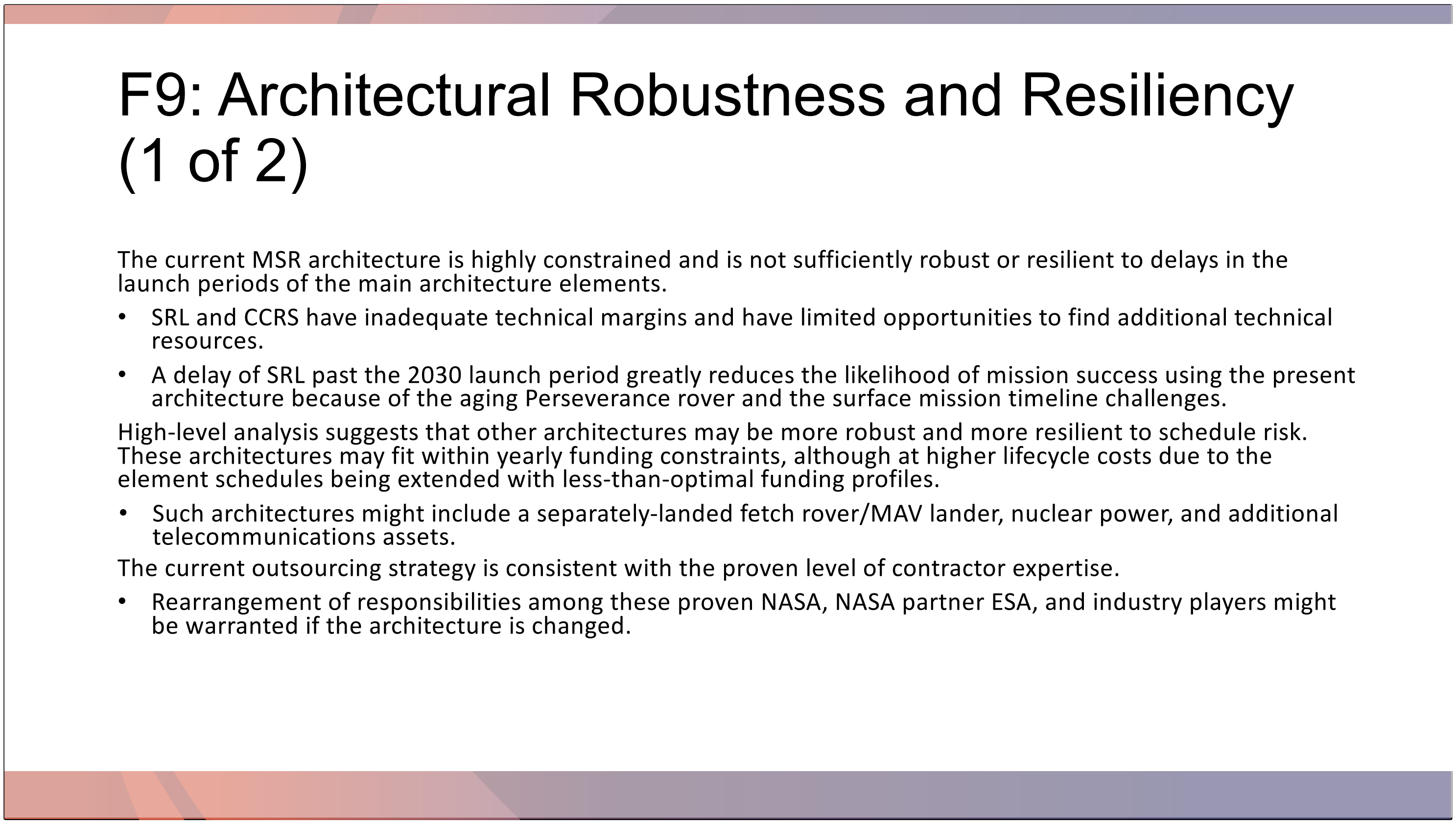
- There is a risk that without an interagency agreement on the subjects of effective biohazard decontamination and intact containment, there will be a failure to approve transfer of the Martian samples to NASA.
- Planetary Protection coordination for Apollo was accomplished by establishing the Interagency Committee on Back Contamination (ICBC).
- MSR currently has no similar interagency coordinating organization or process. The IRB is not aware of any formal contact between NASA and the White House Office of Science and Technology Policy as needed to begin work on the protocols for decision-making and the interagency chain-of-command on safety decisions during MSR landing at the Utah Test and Training Range (UTTR).
- OCS has proposed lunch-and-learn activities with key interagency representatives for the coming year.

R8: NASA Coordination with US Regulatory Agencies on Backward Planetary Protection (2 of 2)

Recommendations:

- (R8.1) All aspects of the MSR design for compliance with backward planetary protection requirements should be reviewed and accepted by NASA’s Office of Safety and Mission Assurance as well as the relevant US regulatory agencies.
  - In addition to UV decontamination of possible Martian biohazards, safety reviews should cover models and testing for breaking the chain of contact and robust containment of non-sterilized material from Mars.
- (R8.2) NASA should initiate engagement with the White House Office of Science and Technology Policy and relevant regulatory agencies in order to establish protocols for decision-making and chain-of-command structure during safety inspection of the Earth Entry System at the UTTR landing site.

When the samples from Mars’ Jezero Crater land on Earth, multiple regulatory agencies will participate in deciding if all unsterilized Martian material is contained and safe for transfer to a receiving facility. Although Jezero Crater is not considered to be currently habitable, there are other locations on Mars where environmental conditions could possibly enable carbon-based life to survive and replicate. Consequently, any samples returned to Earth from Mars must adhere to backward planetary protection requirements that are focused on breaking the chain of contact and utilizing robust containment of all unsterilized material. NASA's technical standards are rigorous and compliant with international standards for planetary protection as established by the Committee on Space Research.



F9: Architectural Robustness and Resiliency (1 of 2)

The current MSR architecture is highly constrained and is not sufficiently robust or resilient to delays in the launch periods of the main architecture elements.

- SRL and CCRS have inadequate technical margins and have limited opportunities to find additional technical resources.
- A delay of SRL past the 2030 launch period greatly reduces the likelihood of mission success using the present architecture because of the aging Perseverance rover and the surface mission timeline challenges.

High-level analysis suggests that other architectures may be more robust and more resilient to schedule risk. These architectures may fit within yearly funding constraints, although at higher lifecycle costs due to the element schedules being extended with less-than-optimal funding profiles.

- Such architectures might include a separately-landed fetch rover/MAV lander, nuclear power, and additional telecommunications assets.

The current outsourcing strategy is consistent with the proven level of contractor expertise.

- Rearrangement of responsibilities among these proven NASA, NASA partner ESA, and industry players might be warranted if the architecture is changed.

The current architecture is intelligently constructed but is also highly constrained. The current architecture is based on an assumed budget and schedule plus other parameters including technical margins that do not seem realistic at this point in the lifecycle. The architecture should be reexamined with respect to all parameters and constraints in order to assure that the mission is both robust and resilient to schedule and other mission constraints.

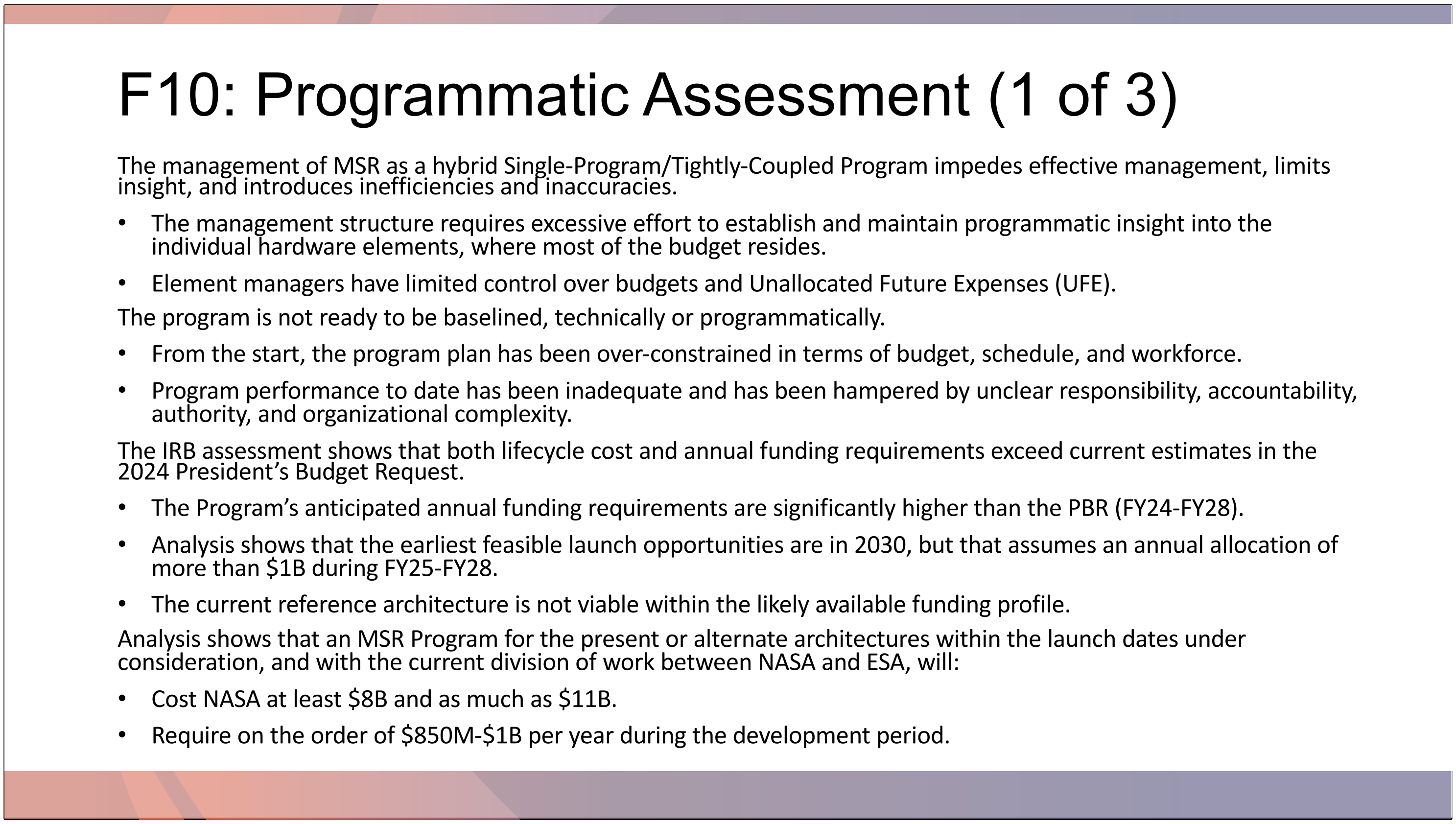
Resilience, in particular schedule resilience, must be a fundamental part of the architecture assessment. Resilience also comes through agility within each element and between elements. This agility requires enough decoupling such that the individual projects are functionally coupled at the mission level but are otherwise fundamentally independent from a developmental perspective.

Robustness should follow from the architecture. Architectural robustness comes through making each system element as individually robust as practical within the constraints imposed by the system-level requirements. Robustness does not necessarily require a blind application of a Class A approach or redundancy mandates. The goal should be a design that is well matched to the systems’ requirements and is focused on resilience that is specific to the mission goals and mission success without added features or complexity.

R9: Architectural Robustness and Resiliency (2 of 2)

Recommendations:

- (R9.1) NASA should examine other potential architectures or variants of the current architecture in order to determine whether there are options that offer greater technical robustness and schedule resilience to launch phasing or launch delays, while fitting within annual budget constraints and lowering programmatic risk.
    - Actively seek and analyze alternatives that might provide larger technical margins than the current architecture while also being technically simpler at the individual project, system, and subsystem levels.
    - The mindset should be simplicity in design, taking advantage of heritage design and approaches, examining mission classification specific to each project element, and execution of a robust cross-cutting V&V program.
    - Enlist independent programmatic analysts to assess each technically viable alternative in order to determine whether the alternative can be implemented with high confidence and lower cost and schedule risk within the annual budget constraints imposed by NASA.
    - Examine which path forward best balances technical and programmatic constraints, given the current status of the Program and the recommendations made in this report.
    - Alternate architectures should be carefully compared to variants of the existing architecture in terms of technical, schedule, and cost risk.
- (R9.2) If a significantly different alternate architecture is determined to be the best way forward for the Program, the MSR Program should consider reallocating responsibilities among participants or adding other experienced and qualified sources when developing an acquisition strategy for the alternatives.



F10: Programmatic Assessment (1 of 3)

The management of MSR as a hybrid Single-Program/Tightly-Coupled Program impedes effective management, limits insight, and introduces inefficiencies and inaccuracies.

- The management structure requires excessive effort to establish and maintain programmatic insight into the individual hardware elements, where most of the budget resides.
- Element managers have limited control over budgets and Unallocated Future Expenses (UFE).

The program is not ready to be baselined, technically or programmatically.

- From the start, the program plan has been over-constrained in terms of budget, schedule, and workforce.
- Program performance to date has been inadequate and has been hampered by unclear responsibility, accountability, authority, and organizational complexity.

The IRB assessment shows that both lifecycle cost and annual funding requirements exceed current estimates in the 2024 President's Budget Request.

- The Program's anticipated annual funding requirements are significantly higher than the PBR (FY24-FY28).
- Analysis shows that the earliest feasible launch opportunities are in 2030, but that assumes an annual allocation of more than $1B during FY25-FY28.
- The current reference architecture is not viable within the likely available funding profile.

Analysis shows that an MSR Program for the present or alternate architectures within the launch dates under consideration, and with the current division of work between NASA and ESA, will:

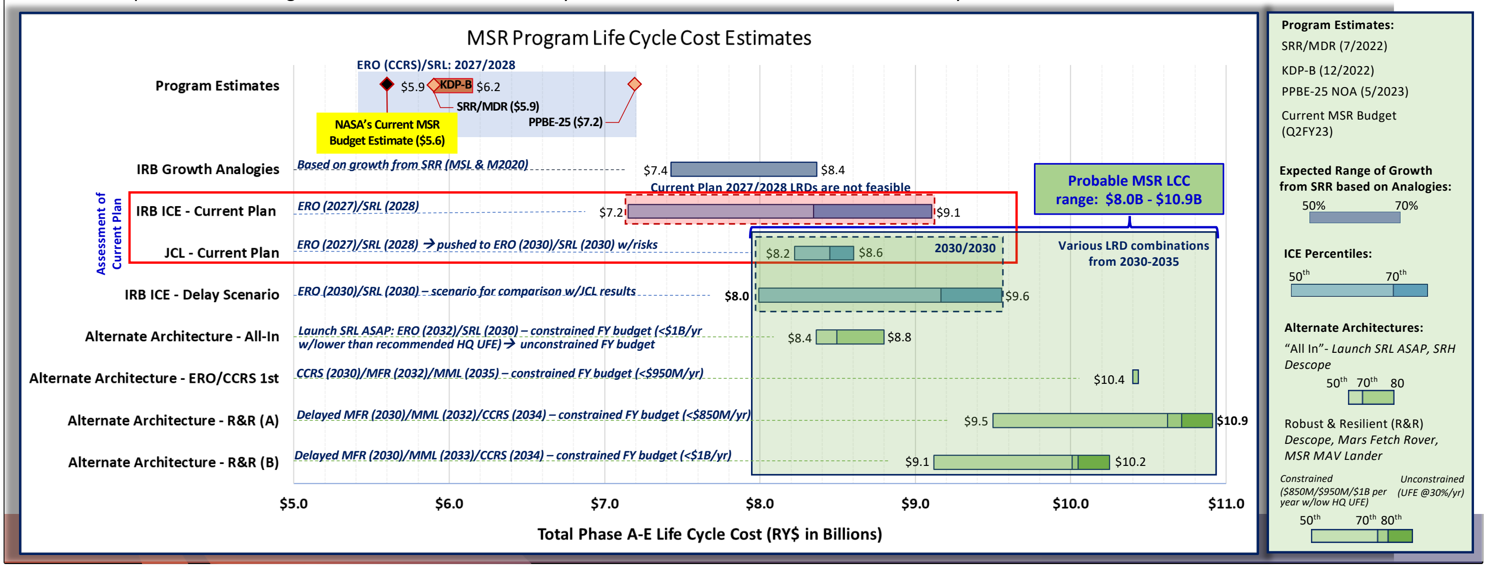
- Cost NASA at least $8B and as much as $11B.
- Require on the order of $850M-$1B per year during the development period.

The MSR Program is currently managing to one Management Agreement (MA) and one Agency Baseline Commitment (ABC) as part of the hybrid Single-Program/Tightly-Coupled Program structure. This structure complicates the management of programmatics by limiting responsibility, accountability, and authority for budget and schedule performance to only the program level (not the project level), thus limiting visibility into cost and schedule performance of the projects against budget and schedule commitments recognized by SMD and the Agency. Given the size, complexity, and cost of each project, SMD and the Agency need separate budget and schedule commitments at the project level.

The program is not ready to be baselined due to continued technical issues that have yet to be resolved and anticipated fiscal year funding streams that are out of line with Program-estimated funding requirements. The earliest feasible launch opportunities will occur in 2030. However, utilizing these opportunities is only possible with adequate fiscal year funding and a total lifecycle cost on the order of $8-11B.

Programmatic Assessment (2 of 3)

- The IRB's independent programmatic assessment shows that **$8-11B** is the probable range (50%-80% confidence level) for the total MSR Program Life Cycle Cost (LCC) - *Range for IRB ICE ERO (2030)/SRL (2030) and Various Alternate Architectures*
  - The IRB's independent programmatic assessment shows that **$8.0-9.6B** is the probable range (50%-80% confidence level) for the total MSR Program LCC with the earliest probable Launch Readiness Dates (LRDs) for both ERO and SRL in 2030.
  - There exist a variety of potential alternate architectures that the program may choose to consider in order to add robustness and resiliency to the Program and/or to operate within the constraints of a fiscal year budget cap. IRB analysis suggests that the alternate architecture solution space has an LCC range of **$8.4-10.9B** with various LRD combinations in the 2030-2035 timeframe.
- The probable cost range demonstrates the uncertainty based on the various scenarios estimated by the IRB.

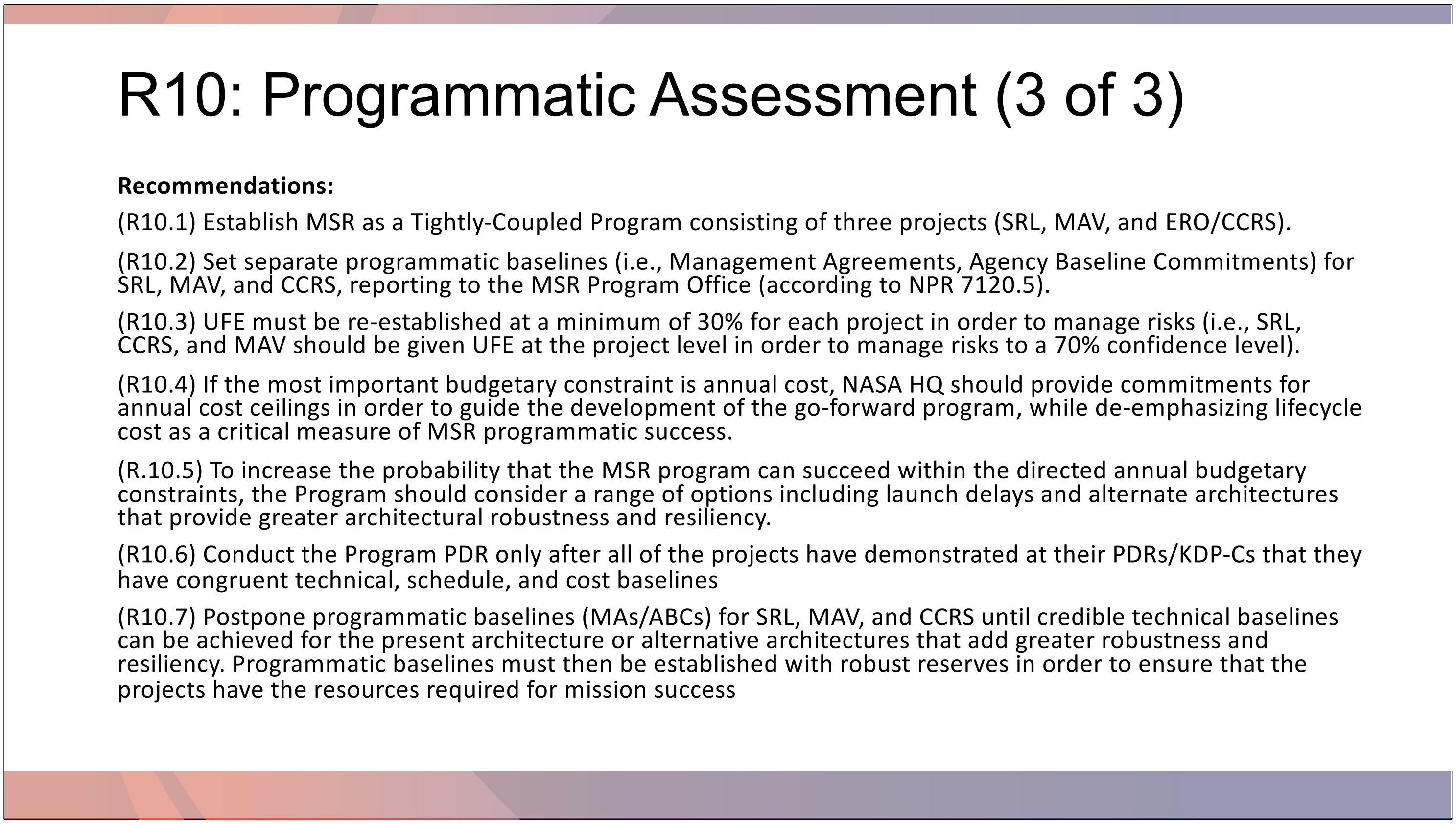


The IRB developed a programmatic assessment of potential MSR Program cost and schedule scenarios, including the program's current plan. While the ICE for the current plan shows a range of costs for the ERO/2027 and SRL/2028 LRDs, the JCL indicates a very low probability of achieving the current LRDs. The earliest likely LRDs for both ERO and SRL are in 2030. The subsequent IRB ICE for the delayed (2030/2030) scenario illustrates a rephased cost plan for comparison. This scenario, combined with potential alternate architectures, provides a probable lifecycle cost range of approximately $8-11B.

The alternate architectures considered were not detailed concepts and were intended only to represent a potential solution space for programmatic analysis. The alternate architectures included decoupled projects (where launches are not dependent on one another) with fiscal year budget scenarios that are either constrained (up to $850M, $950M, or $1B/fiscal year) or unconstrained. Scenarios included:

- The "All In" approach, which prioritized SRL to launch as soon as possible with helicopters removed but retaining the arm.
- The "Robust and Resilient (R&R)" approaches, which disaggregated the landed systems into two missions: 1) MSR Fetch Rover (MFR), which includes a 2xMER rover carrying the OS, scaled-down Skycrane EDL, and STHS, and 2) MSR MAV Lander (MML), which includes the MAV and a MAV landing/launch system using a scaled-up Skycrane EDL. The helicopters and the arm were removed from the MAV lander due to the addition of the MFR. One option launched ERO/CCRS first, with a constrained funding level of $950M/year. Another set of options launched the landed systems first and examined the impact of two constrained funding levels – $850M/year and $1B/year.

Overall, the IRB analysis suggests the alternate architecture solution space has an LCC range of $8.4-10.9B with various LRD combinations in the 2030-2035 timeframe.



R10: Programmatic Assessment (3 of 3)

Recommendations:

(R10.1) Establish MSR as a Tightly-Coupled Program consisting of three projects (SRL, MAV, and ERO/CCRS).

(R10.2) Set separate programmatic baselines (i.e., Management Agreements, Agency Baseline Commitments) for SRL, MAV, and CCRS, reporting to the MSR Program Office (according to NPR 7120.5).

(R10.3) UFE must be re-established at a minimum of 30% for each project in order to manage risks (i.e., SRL, CCRS, and MAV should be given UFE at the project level in order to manage risks to a 70% confidence level).

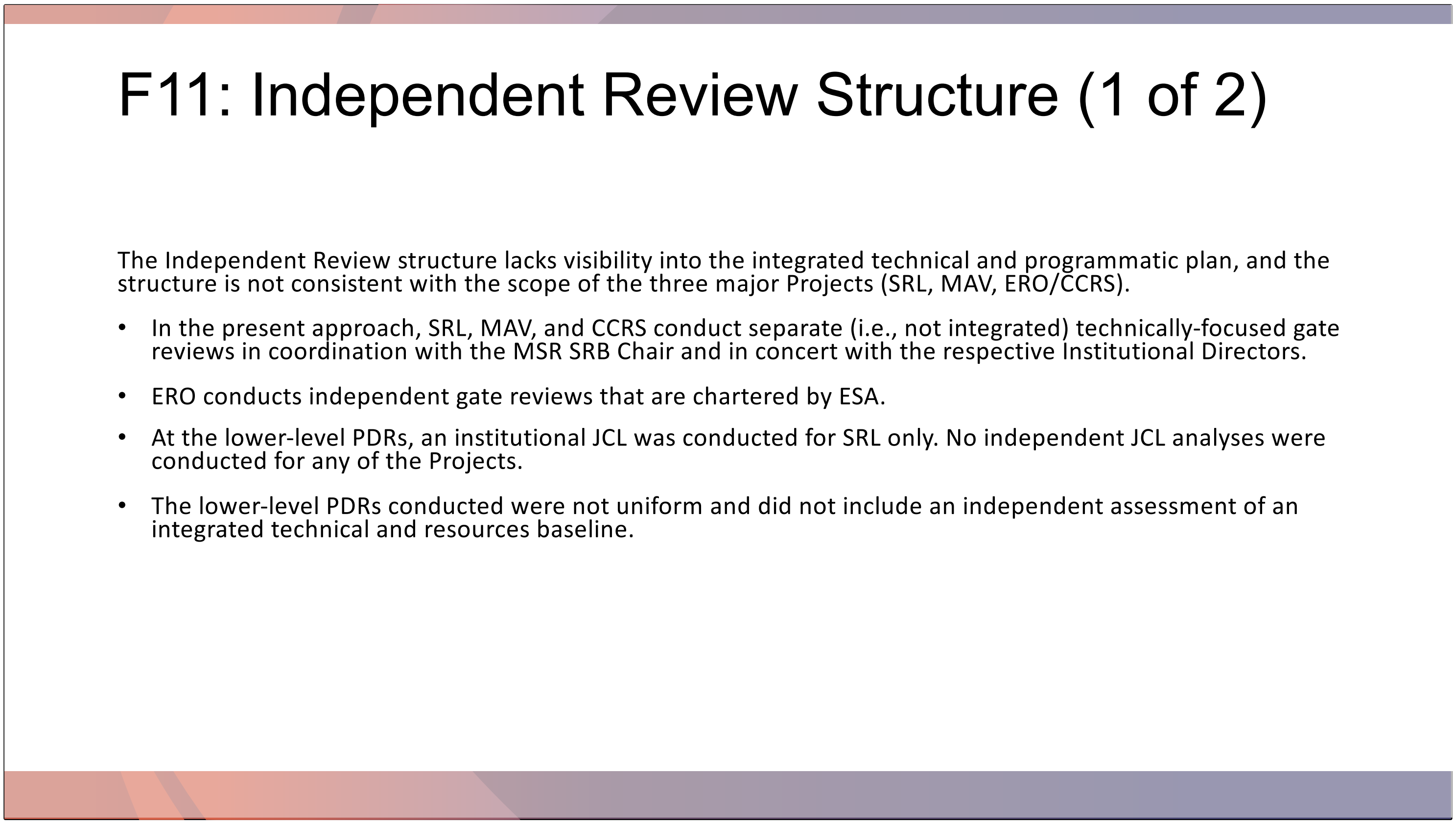
(R10.4) If the most important budgetary constraint is annual cost, NASA HQ should provide commitments for annual cost ceilings in order to guide the development of the go-forward program, while de-emphasizing lifecycle cost as a critical measure of MSR programmatic success.

(R.10.5) To increase the probability that the MSR program can succeed within the directed annual budgetary constraints, the Program should consider a range of options including launch delays and alternate architectures that provide greater architectural robustness and resiliency.

(R10.6) Conduct the Program PDR only after all of the projects have demonstrated at their PDRs/KDP-Cs that they have congruent technical, schedule, and cost baselines

(R10.7) Postpone programmatic baselines (MAs/ABCs) for SRL, MAV, and CCRS until credible technical baselines can be achieved for the present architecture or alternative architectures that add greater robustness and resiliency. Programmatic baselines must then be established with robust reserves in order to ensure that the projects have the resources required for mission success

Allowing SRL, MAV, and CCRS to be managed as separate projects under a revised, Tightly-Coupled Program structure will enable each project to have responsibility, authority, and accountability over its portion of the program work. The Tightly-Coupled Program structure will also enable each project to manage to its own MA/ABC with individual project control over budgets, reserves/UFE, and schedules, while reporting to the MSR Program Office as appropriate and in accordance with NPR 7120.5F. Schedules for each project should be managed separately but cooperatively, and should be carefully integrated at the Program level. Baselines for each project should not be set until budgetary constraints are aligned with credible technical baselines that have been carefully studied through an analysis of alternative architectures that add robustness and resiliency for the enhancement of mission success.



F11: Independent Review Structure (1 of 2)

The Independent Review structure lacks visibility into the integrated technical and programmatic plan, and the structure is not consistent with the scope of the three major Projects (SRL, MAV, ERO/CCRS).

- In the present approach, SRL, MAV, and CCRS conduct separate (i.e., not integrated) technically-focused gate reviews in coordination with the MSR SRB Chair and in concert with the respective Institutional Directors.
- ERO conducts independent gate reviews that are chartered by ESA.
- At the lower-level PDRs, an institutional JCL was conducted for SRL only. No independent JCL analyses were conducted for any of the Projects.
- The lower-level PDRs conducted were not uniform and did not include an independent assessment of an integrated technical and resources baseline.

The current program has struggled with performing independent reviews in a way that is consistent with the NPR 7120.5F requirement such that all of the key program elements receive thorough and independent review. Despite best intentions, IRTs at the institutional level are necessary but not sufficient to assure comprehensive and uniform review. For example, SRL, MAV, and CCRS are not presently subject to a review process that meets the standards that are expected of a Class A mission of this magnitude and complexity.

A key step in addressing the shortcomings of the review structure is to create a tightly-coupled program that accommodates SRL, MAV, and CCRS as separate projects such that each project has an SRB functioning within the requisite 7120.5F framework while also supporting the Program-level MSR integration requirements. In this way, all key elements of the project will be subject to a uniform standard of review and will be subject to a uniform level of programmatic reporting and analysis that can then be effectively rolled up into the Program-level assessment.

R11: Independent Review Structure (2 of 2)

Recommendations:

- (R11.1) As a Tightly-Coupled Program, establish separate SRBs for SRL, MAV, and CCRS that provide independent programmatic assessment (including JCLs) and adhere to conflict-of-interest and independence screening as described in the NASA SRB Handbook.
- (R11.2) The program SRB should comprise a cross-cut of independent program-level experts combined with the Chairs and a subset of other relevant members from the individual projects SRBs.
- (R11.3) Each MSR Independent Review Team (IRT) activity should be retained with the addition of SRB cross-cutting support but with the traditional focus of supporting the needs of the executing institution.
- (R11.4) Perform SRB-chaired PDRs and establish individual baselines for each of the Projects.
- (R11.5) In accordance with NPR 7120.5F, JCL analysis is required at KDP-C for the Projects (SRL, MAV, CCRS) with the Program-level SRB integrating those analyses into a broader programmatic assessment of the end-to-end effort at KDP-II.
- (R11.6) PDR entrance and success criteria leading to KDP-C should include an assessment of the integrated technical and resources baseline.
- (R11.7) The Program and each MSR Project (SRL, MAV, and CCRS) should report to their respective SRBs on a quarterly basis.

F12: Culture and Communication (1 of 2)

Each of the contributing organizations has a dramatically different engineering and management culture as well as a strong basis to their historical mission experience. This influences the organizations' approaches to risk management, communications, testing, and verification and validation. Miscommunication can arise frequently across these cultural lines.

- The Program introduced what it calls a "Federated Model" for collaboration in order to give each organization autonomy over its engineering, assurance, and management processes. The Program's intent was to avoid the perception that one organization is controlling another. However, this arrangement has exacerbated miscommunications by reifying distinctions between organizational cultures. This arrangement has limited penetration into shared technical issues.
- Amid so many convoluted partnerships, members of MSR have a limited ability to develop deep cross-cultural literacy and the understanding that is necessary to work effectively across institutional lines.
- Certain elements of the MSR organizational structure are exacerbating cultural differences and miscommunications. Issues include multi-institutional politics, confusing phase and domain reporting pathways (i.e., cross-organizational phase leads with limited authority), and limited interactions between engineers in the ranks across these organizations.
- A shared mission culture can help to ease miscommunications. Currently, there is no shared "MSR mission" identity across all members. It is noted that the ESA team has shown the emergence of a shared "MSR subculture," and JPL-SRL/MSFC-MAV are developing deeper understanding.
- The co-located nature of the Program Office, the SRL development, and CCRS components at JPL are creating additional confusions and limitations on communicating directly with their appropriate chain of command.
- The team normalized the limited in-person interactions experienced during COVID-19 such that it has persisted post-lockdown. The MSR team has never met in person. Most team members we spoke with have not visited the institutions and individuals with which they are collaborating most closely (i.e., MSFC and JPL). Limited in-person interactions limits the development of cross-cultural visibility and understanding.

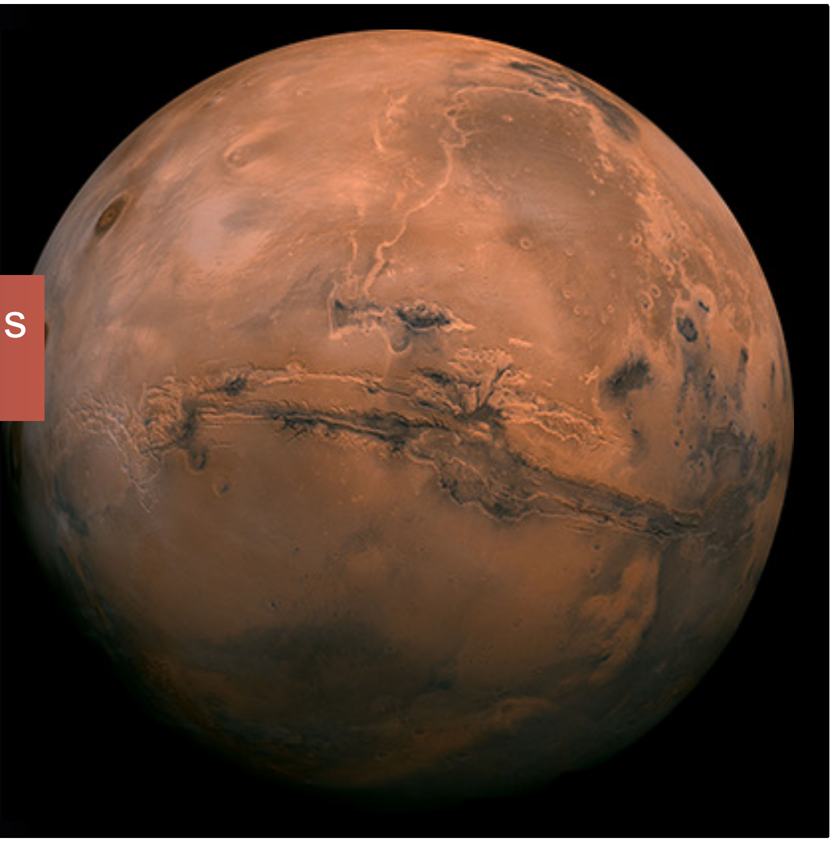
MSR team members understand the importance of culture to their mission. Many team members are meeting the challenges of working across the cultures of their respective organizations. These findings highlight areas where a deeper understanding of the cultural differences can dramatically improve MSR's response to these challenges.

R12: Culture and Communication (2 of 2)

Recommendations: Clarifying the organizational structure, simplifying programmatic partnerships, investing in cultural interfaces with depth, enabling visibility and exchange across organizations, and providing intercultural training will go a long way toward resolving these issues and providing technical penetration on shared issues from campaign planning to shared V&V plans.

- [R.12.1] Establish SRL/MAV and ERO/CCRS as individual programmatic partners in order to allow each grouping to focus on building intercultural bridges between organizations.
- [R.12.2] Clarify the domain and phase structures, enable multi-institutional group members to communicate directly and make decisions across institutions, and empower those groups to resolve conflicts. This approach will develop cross-site visibility and shared understanding.
- [R.12.3] Invest in periodic and sustained in-person interactions between engineers working on parallel or related tasks across programmatic partners (i.e., the domains). The MSR Program Office should fund and facilitate team members visiting their collaborators in other institutions as part of developing intercultural fluency and inter-organizational visibility. In-person gatherings of sub-groups with multi-institutional representations should occur at a regular cadence in order to supplement online meetings.
- [R.12.4] The MSR Program should facilitate intercultural training among team members in order to facilitate conflict resolution and better understanding of engineering and management issues.
- [R.12.5] Place team members on location at a collaborating institution, as ESA has done at Goddard Space Flight Center.
- [R.12.6] Document multi-organizational decisions and changes in order to ensure robust multi-institutional communication, baseline control, and flowdown.

Additional Important Findings and Recommendations



F13: Verification and Validation (1 of 2)

The MSR Verification and Validation (V&V) program is not sufficiently mature. Evidence indicates that the integrated V&V program is underscoped and underfunded.

- MSR has highly-coupled and complex elements (SRL, ERO, MAV), which require carefully considered and possibly unique approaches to V&V.
- MSR appears to be following the precedent of past programs in underscoping V&V, including the development of a robust V&V plan for fault management.
- Examples of V&V concerns:
  - No integrated test is planned for CCRS capture and orientation of the OS in Mars orbit.
  - The SRL/MAV interface test (VECTOR plus ignition test) is not well defined.
  - Only one funded test is planned for SRL parachute deployment, even though this is the largest and most complex parachute ever flown on a planetary mission.
  - FM CCRS has no dynamic environmental tests with the ERO spacecraft after final integration. Concerns include dynamic couplings and workmanship verification.
  - The Sample Transfer and Handling System requires a V&V plan (including test and closed-loop verification at different physical locations) that is very complex, poorly defined, and resides under split responsibilities.

R13: Verification and Validation (2 of 2)

Recommendations:

- (R13.1) Develop integrated and detailed V&V plans (with credible schedules and costs) to a level of confidence that is appropriate for this flagship mission prior to completion of preliminary design review activities.
- (R13.2) Ensure that each integrated V&V activity has properly recognized and scheduled the development of all required ancillary elements including flight software, ground software, ground support equipment, hardware-in-the-loop, testbeds, and simulations.
- (R13.3) Ensure clear system V&V leadership and coordination across elements. Ensure reasonable time and staffing allocations to complete proper V&V of the integrated systems.
- (R13.4) Address fault management and contingency planning in the development of detailed V&V plans.

F14: Cross-Organization Engineering Management (1 of 2)

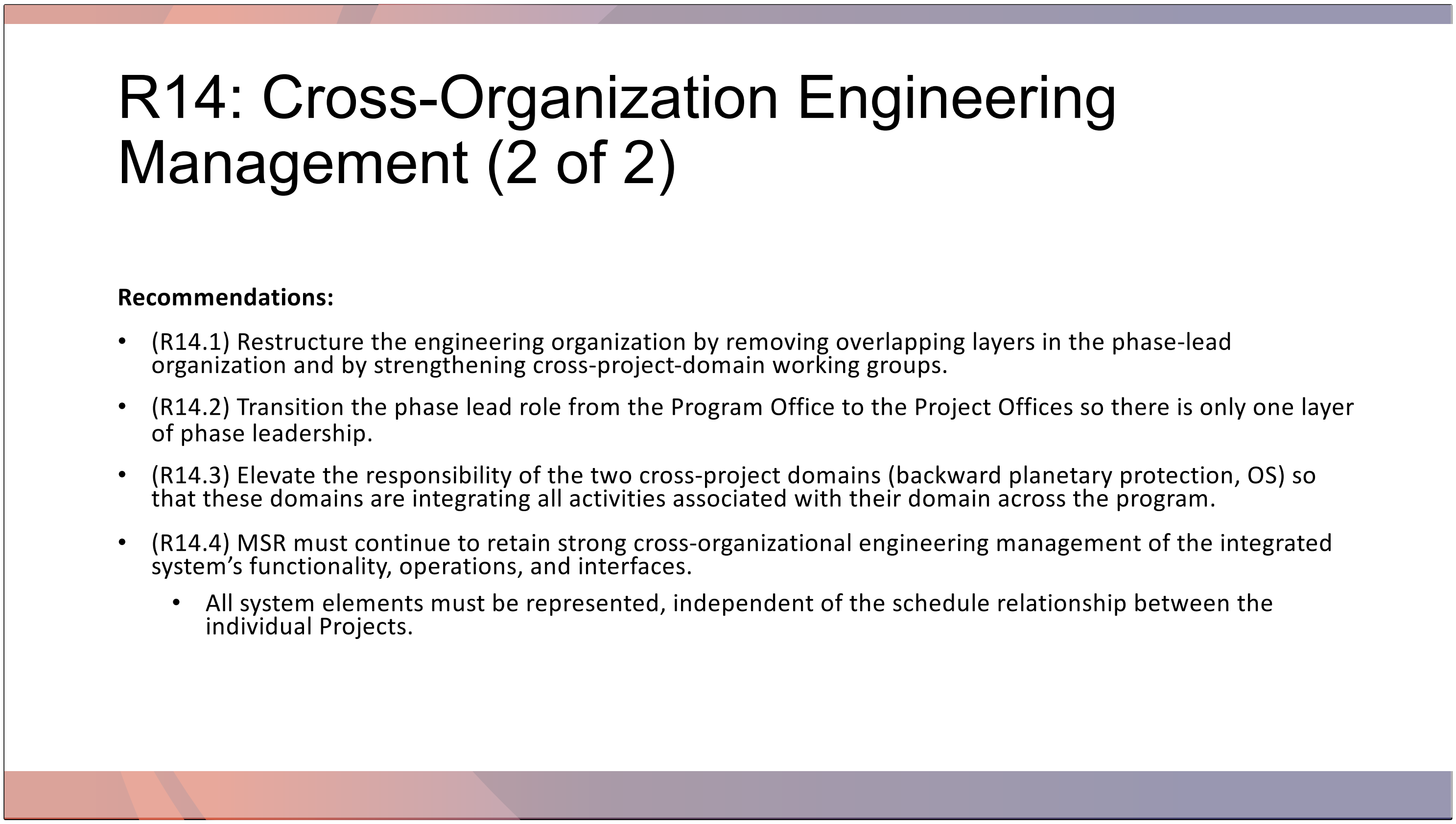
A multi-layered phase-lead engineering approach was intended to provide oversight for the entire MSR campaign and to overlap with the cross-organizational/project domain engineering working groups. The approach has resulted in a large and complex engineering organization with multiple paths of communication and reporting, unclear lines of responsibility and authority, and a significant amount of coordination required among the various teams.

- For example, the launch, rendezvous, and capture phase organization includes multiple sub-phases due to the complex integrated and time-dependent operations of SRL and ERO.

JPL’s phase-lead engineering organization approach has proven to be an excellent model for complex functional mission development and operational planning for JPL-run missions. However, the model has been expanded greatly for MSR to also include the ERO/CCRS mission. This expanded model adds an extra layer of phase leads at the Program layer. This additional layer was introduced with the intention of eliminating gaps between mission phases at the campaign level. However, this structure is causing more confusion and adding extra layers of required review, communication, and coordination. Additionally, this structure further dilutes accountability and in sum will have a negative impact on both the project and mission's overall success.

The phase-lead model is intended to have a single person with responsibility and authority for the success of a specific part of the mission. This model has been expanded with three program-level phase positions created to oversee operational planning and mission design, where there are interface handoffs and overlap between ERO/CCRS and SLR/MAV. Additionally, there are now nested or sub-phase leads reporting to these program leads, with co-leads at contributing organizations. This requires significant coordination and communication, resulting in a potentially unproductive workload on team members. Unlike the phase lead model of prior JPL missions, MSR’s multi-mission architecture and multi-layered phase organization have also put phase leads in the difficult position of having responsibility but no real authority to direct phase team members who are from outside organizations.

The phase lead structure also overlaps with and is at odds with the domain working groups. These groups were created with the intention of handling the cross-organization and engineering interfaces between the Projects. The roles and responsibilities between phase leads and domain leads are also poorly defined and create additional organizational confusion.



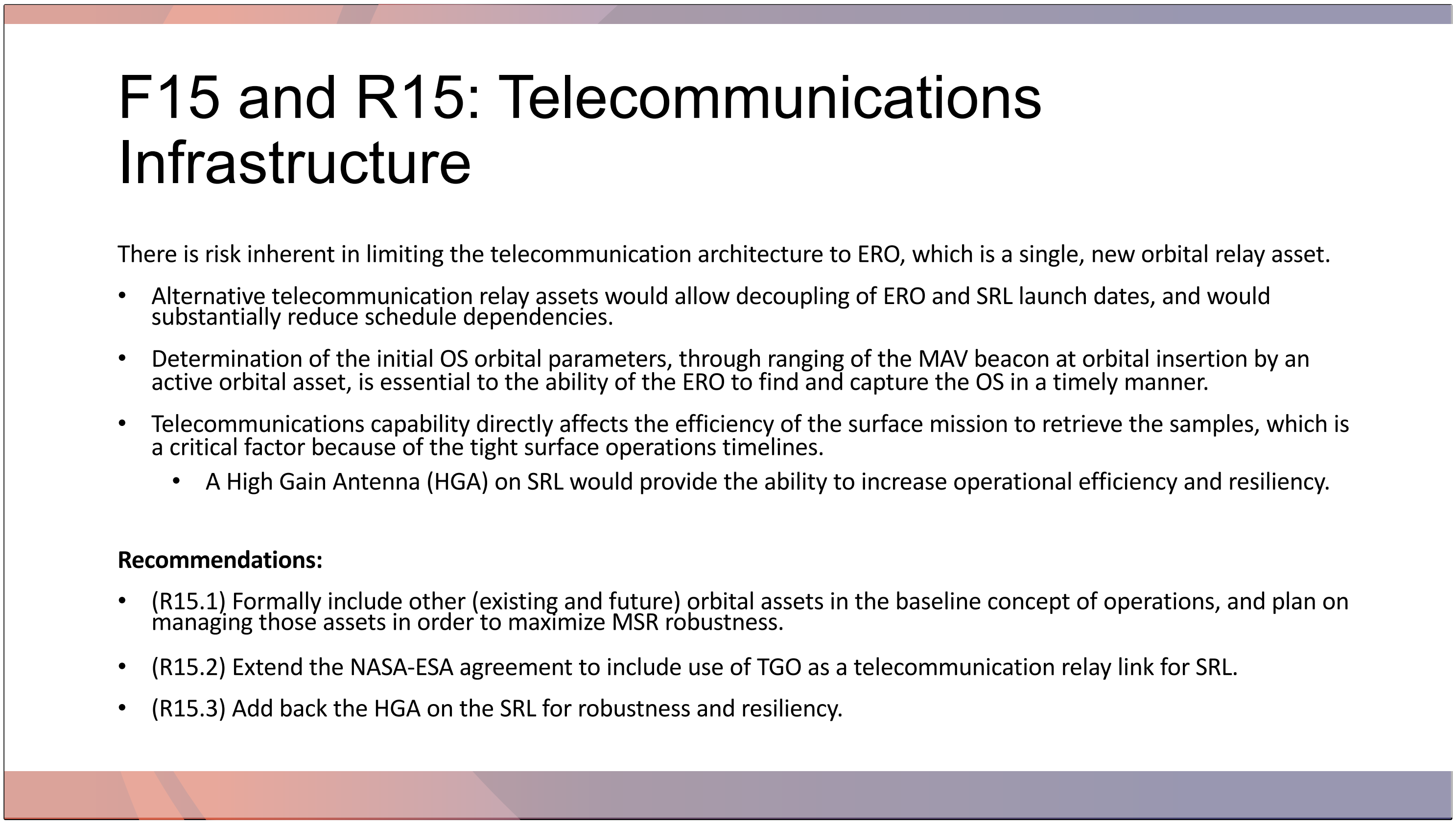
R14: Cross-Organization Engineering Management (2 of 2)

Recommendations:

- (R14.1) Restructure the engineering organization by removing overlapping layers in the phase-lead organization and by strengthening cross-project-domain working groups.
- (R14.2) Transition the phase lead role from the Program Office to the Project Offices so there is only one layer of phase leadership.
- (R14.3) Elevate the responsibility of the two cross-project domains (backward planetary protection, OS) so that these domains are integrating all activities associated with their domain across the program.
- (R14.4) MSR must continue to retain strong cross-organizational engineering management of the integrated system’s functionality, operations, and interfaces.
  - All system elements must be represented, independent of the schedule relationship between the individual Projects.

The phase and domain lead organization should be restructured according to the recommended decoupling of the ERO and SRL missions. This recommendation aims to ensure thorough consideration of the existing organizational structure's ramifications, encompassing both the negative and positive aspects of the structure’s overlapping roles and responsibilities.

The program needs to adopt alternative phase/domain structures that are more easily communicable within the team, entail fewer leaders and team members needing constant updates, and involve fewer review and coordination meetings while still effectively covering the necessary mission phases. This approach will allow JPL to focus on managing and stabilizing campaign-level cross-project interfaces, with individual Projects having the autonomy and clear authority to manage their phases and design. Cross-organizational working groups need to have representation from all contributing organizations, regardless of technical and programmatic coupling. This representation will efficiently increase awareness of technical issues and solutions. For the updated organization, the decision-making authority, accountability, and responsibility of each phase and domain element at the Project and Program level should be clearly documented and communicated internally to Project and Program team members and also to external stakeholders.



F15 and R15: Telecommunications Infrastructure

There is risk inherent in limiting the telecommunication architecture to ERO, which is a single, new orbital relay asset.

- Alternative telecommunication relay assets would allow decoupling of ERO and SRL launch dates, and would substantially reduce schedule dependencies.
- Determination of the initial OS orbital parameters, through ranging of the MAV beacon at orbital insertion by an active orbital asset, is essential to the ability of the ERO to find and capture the OS in a timely manner.
- Telecommunications capability directly affects the efficiency of the surface mission to retrieve the samples, which is a critical factor because of the tight surface operations timelines.
  - A High Gain Antenna (HGA) on SRL would provide the ability to increase operational efficiency and resiliency.

Recommendations:

- (R15.1) Formally include other (existing and future) orbital assets in the baseline concept of operations, and plan on managing those assets in order to maximize MSR robustness.
- (R15.2) Extend the NASA-ESA agreement to include use of TGO as a telecommunication relay link for SRL.
- (R15.3) Add back the HGA on the SRL for robustness and resiliency.

Orbit knowledge is a function of the initial state knowledge and the time of propagation. These parameters do not change meaningfully after delivery of the OS to orbit by the MAV. The key is the observation of the MAV beacon by orbital telecommunications assets to confirm adequate orbit parameters. This knowledge will confirm a ~10 year orbital lifetime of the OS.

F16 and R16: Helicopter Accommodation Risk Balance

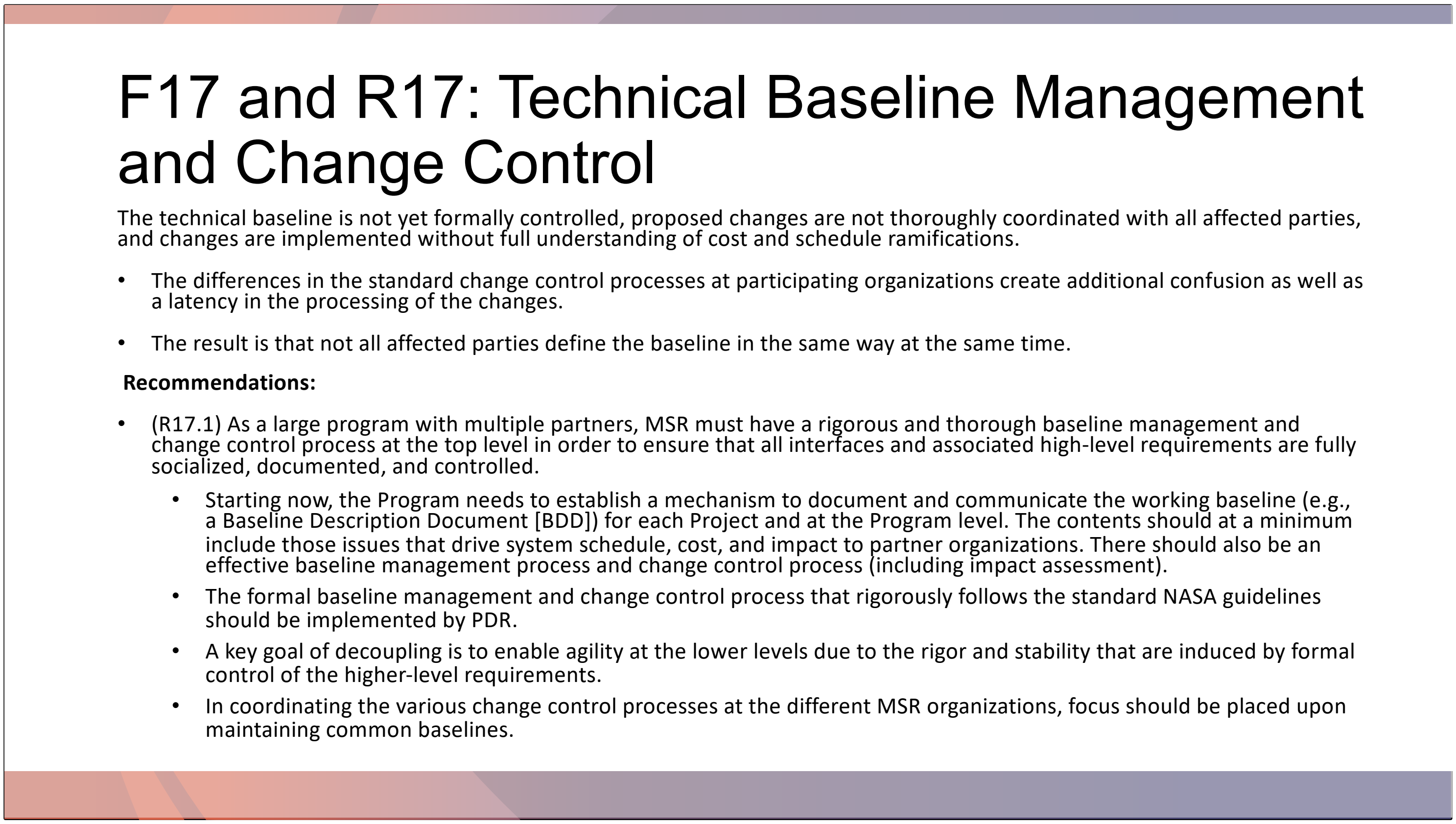
The current architecture includes helicopters as a backup capability to deliver samples to the SRL out of concern for Perseverance's reliability and longevity. This backup adds cost and poses accommodation challenges that add risk to SRL.

- The need for a backup sample delivery capability to SRL is clear in the present architecture. While direct delivery of samples by Perseverance provides more samples and is lower risk because it is a more controlled operation, the long-term viability of Perseverance cannot be assured.
- If Perseverance loses its ability to deliver samples:
  - A single helicopter is currently enough to deliver the backup Three Forks 10 sample cache (although with less than desired unencumbered timeline margin). One helicopter alone provides most of the benefit to the overall MSR reliability.
  - Two helicopters are required in order to meet Class B equivalent reliability via the redundant helicopters, and to allow full surface timeline margin to be maintained early in development.
- Helicopter capability is limited by Mars atmosphere and site safety conditions. Accommodation on SRL is significantly constrained by the small amount of volume and mass available and by unique initial release and takeoff challenges.

Recommendation:

- (R16.1) If mass and accommodation complexity of two helicopters are driving the SRL design in a way that jeopardizes design closure of the system and/or creates significant risks (to SRL in general, or helicopter accommodation in particular), a single higher-reliability helicopter accommodation solution is better than two compromised helicopters (or no helicopter) in order to preserve the capability as part of the present architecture.

The sample return helicopter (SRH) helicopter accommodation on the Sample Return Lander (SRL) is very different from Mars Perseverance and Ingenuity heritage since the only viable location for the helicopters on SRL is on top of the lander. The aerodynamics associated with this location is quite different from the flat surface take-off that Ingenuity has demonstrated to date on Mars. The location is also significantly volume and mass constrained location, creating a new initial take-off environment with complex local geometry.



F17 and R17: Technical Baseline Management and Change Control

The technical baseline is not yet formally controlled, proposed changes are not thoroughly coordinated with all affected parties, and changes are implemented without full understanding of cost and schedule ramifications.

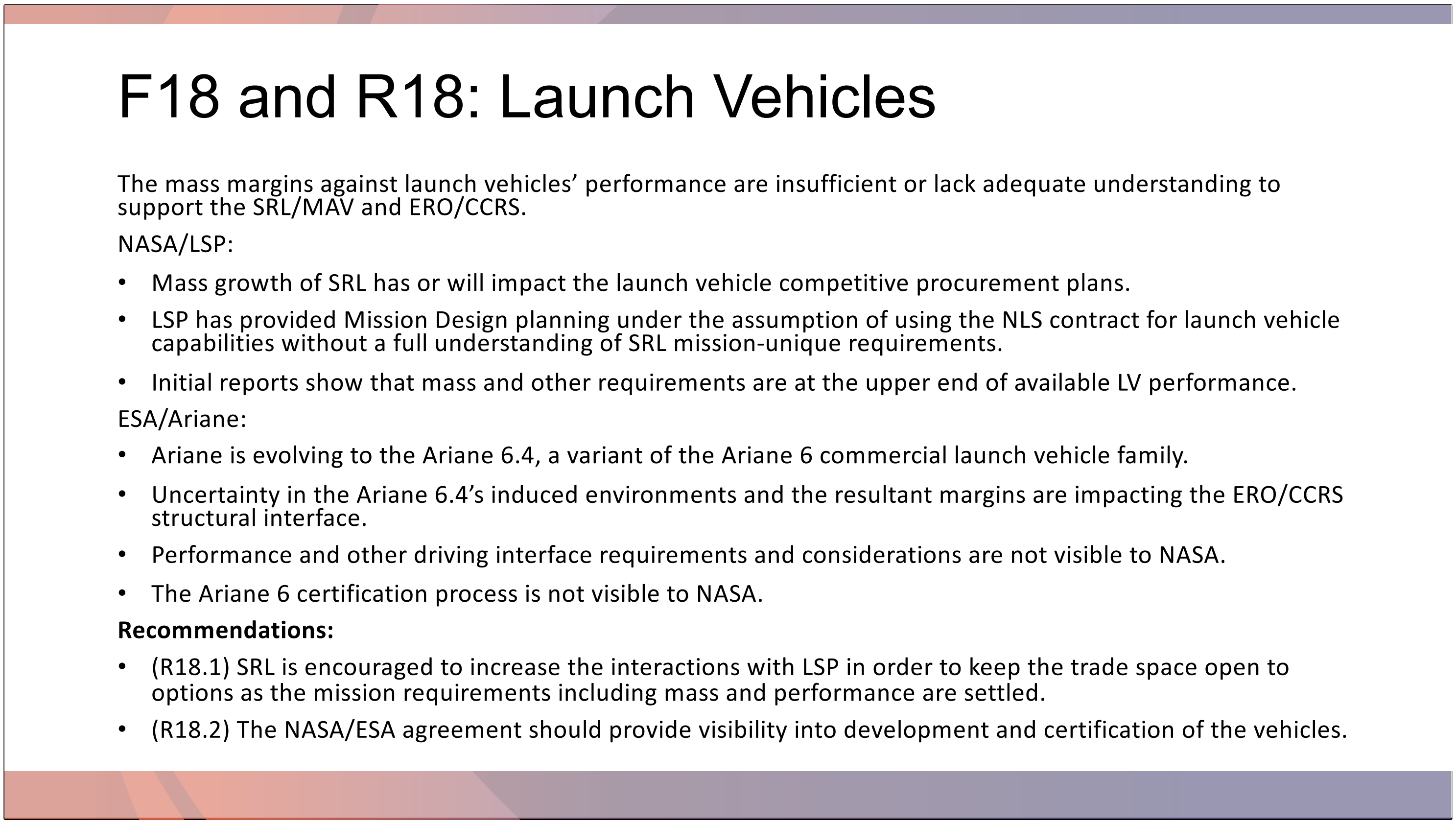
- The differences in the standard change control processes at participating organizations create additional confusion as well as a latency in the processing of the changes.
- The result is that not all affected parties define the baseline in the same way at the same time.

Recommendations:

- (R17.1) As a large program with multiple partners, MSR must have a rigorous and thorough baseline management and change control process at the top level in order to ensure that all interfaces and associated high-level requirements are fully socialized, documented, and controlled.
  - Starting now, the Program needs to establish a mechanism to document and communicate the working baseline (e.g., a Baseline Description Document [BDD]) for each Project and at the Program level. The contents should at a minimum include those issues that drive system schedule, cost, and impact to partner organizations. There should also be an effective baseline management process and change control process (including impact assessment).
  - The formal baseline management and change control process that rigorously follows the standard NASA guidelines should be implemented by PDR.
  - A key goal of decoupling is to enable agility at the lower levels due to the rigor and stability that are induced by formal control of the higher-level requirements.
  - In coordinating the various change control processes at the different MSR organizations, focus should be placed upon maintaining common baselines.

All MSR organizations must operate under a common set of assumptions and possess comprehensive awareness of the trades and issues that affect all stakeholders. Technical trades, issues, and decisions that impact fundamental assumptions should be swiftly communicated and mutually agreed upon before more formal and time-consuming modifications are made to configuration-controlled documentation.

MSR campaign and project systems engineering should establish an agile and efficient method for documenting and disseminating design and interface assumptions and decisions. This process should evolve to be fully in alignment with NASA standards by the Preliminary Design Review (PDR). For example, a baseline description document can serve as a rapid means of conveying the current baseline before the more formal configuration control change process is initiated. Disciplinary analysis teams and design teams could then cite this document as the foundation for their modeling and analysis outcomes. Any potential trades or deviations from the baseline would have a clearly defined reference design as a starting point. The baseline control process needs to consider partner organization processes and any MSR organizational changes related to the recommended decoupling of the ERO and SRL missions.



F18 and R18: Launch Vehicles

The mass margins against launch vehicles’ performance are insufficient or lack adequate understanding to support the SRL/MAV and ERO/CCRS.

NASA/LSP:

- Mass growth of SRL has or will impact the launch vehicle competitive procurement plans.
- LSP has provided Mission Design planning under the assumption of using the NLS contract for launch vehicle capabilities without a full understanding of SRL mission-unique requirements.
- Initial reports show that mass and other requirements are at the upper end of available LV performance.

ESA/Ariane:

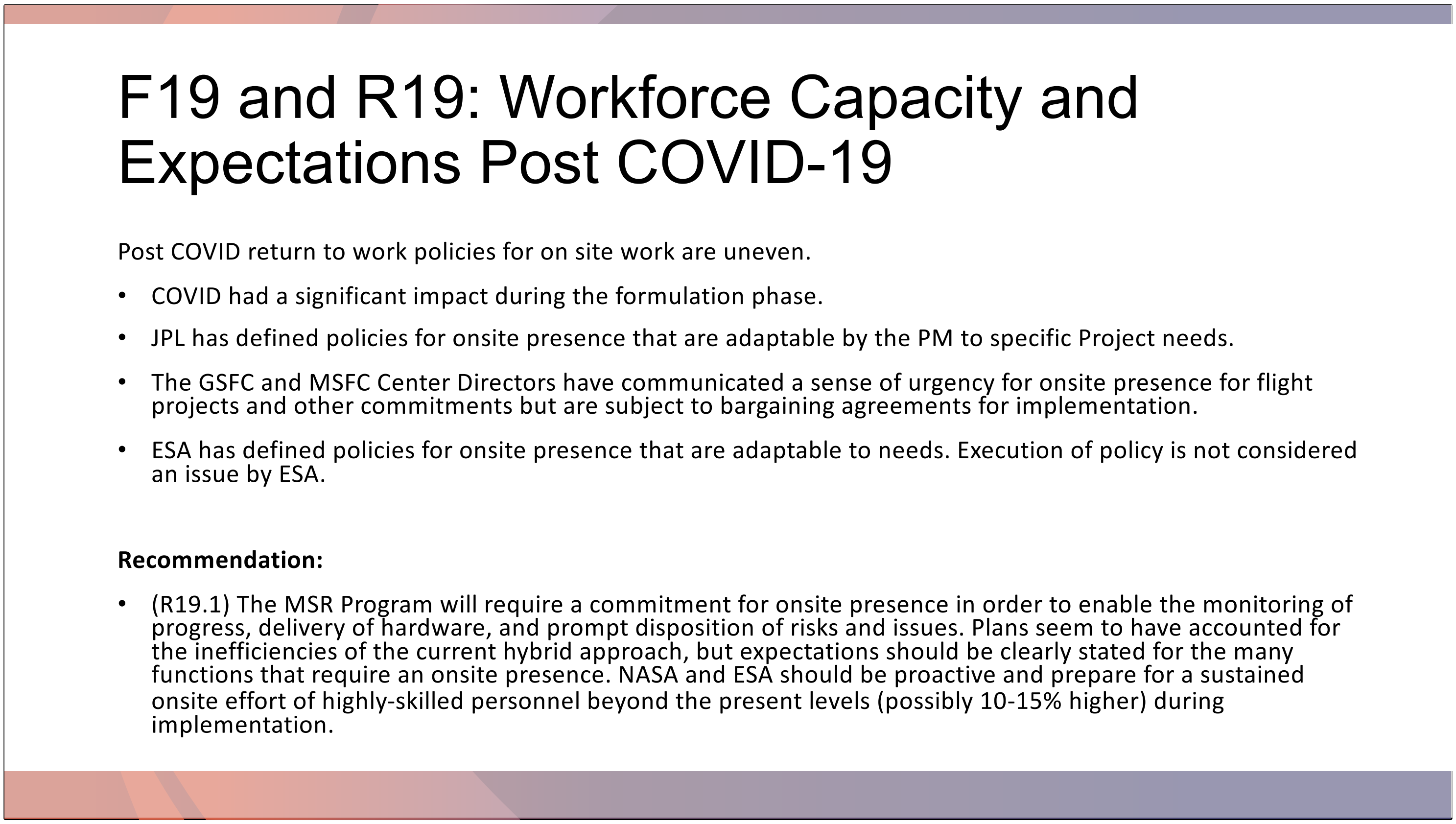
- Ariane is evolving to the Ariane 6.4, a variant of the Ariane 6 commercial launch vehicle family.
- Uncertainty in the Ariane 6.4’s induced environments and the resultant margins are impacting the ERO/CCRS structural interface.
- Performance and other driving interface requirements and considerations are not visible to NASA.
- The Ariane 6 certification process is not visible to NASA.

Recommendations:

- (R18.1) SRL is encouraged to increase the interactions with LSP in order to keep the trade space open to options as the mission requirements including mass and performance are settled.
- (R18.2) The NASA/ESA agreement should provide visibility into development and certification of the vehicles.

The Launch Services Program (LSP) Office at NASA/KSC provides launch and payload processing services for NASA robotic missions, including launch vehicle mission assurance. LSP partners with USSF and NRO to fulfill its role. This role includes commercial Acquisition, Program Management, Analysis (including targeted IV&V), Launch Vehicle Certification, Engineering (Fleet insight @ Design and Production centers including targeted RO locations), Mission Integration (including independent requirement verifications), and Launch Operations.

LSP has provided Mission Design planning for the past two years. This planning was done under the assumption of NLS launch vehicle capabilities without consideration of mission-unique impacts to launch vehicle performance requirements. Initial reports from all LV providers as part of the Coupled Loads Analysis (CLA) are that challenging mission requirements include mass, components below the separation plane, and potential thermal control needs. Backup 2030 opportunities are equally or more challenging.



F19 and R19: Workforce Capacity and Expectations Post COVID-19

Post COVID return to work policies for on site work are uneven.

- COVID had a significant impact during the formulation phase.
- JPL has defined policies for onsite presence that are adaptable by the PM to specific Project needs.
- The GSFC and MSFC Center Directors have communicated a sense of urgency for onsite presence for flight projects and other commitments but are subject to bargaining agreements for implementation.
- ESA has defined policies for onsite presence that are adaptable to needs. Execution of policy is not considered an issue by ESA.

Recommendation:

- (R19.1) The MSR Program will require a commitment for onsite presence in order to enable the monitoring of progress, delivery of hardware, and prompt disposition of risks and issues. Plans seem to have accounted for the inefficiencies of the current hybrid approach, but expectations should be clearly stated for the many functions that require an onsite presence. NASA and ESA should be proactive and prepare for a sustained onsite effort of highly-skilled personnel beyond the present levels (possibly 10-15% higher) during implementation.

The Psyche IRB (2022) revealed communication and coordination challenges imposed by the pandemic lockdown circumstances and the lack of collocated work. While MSR is in an earlier phase of development, decisions have been made with poor visibility. This situation establishes a cultural pattern of collaboration under poor communication practices. Research has repeatedly shown that repetitive, singular, or solo-authored tasks are best done remotely, but integrative projects and planning phases require in-person time for effective and efficient completion. At the time of writing of this report, center work-from-home capabilities vary and are influenced by local labor negotiations as opposed to a result of attending to the requirements of the job at hand or broader workplace reforms.

F20 and R20: Supply Chain

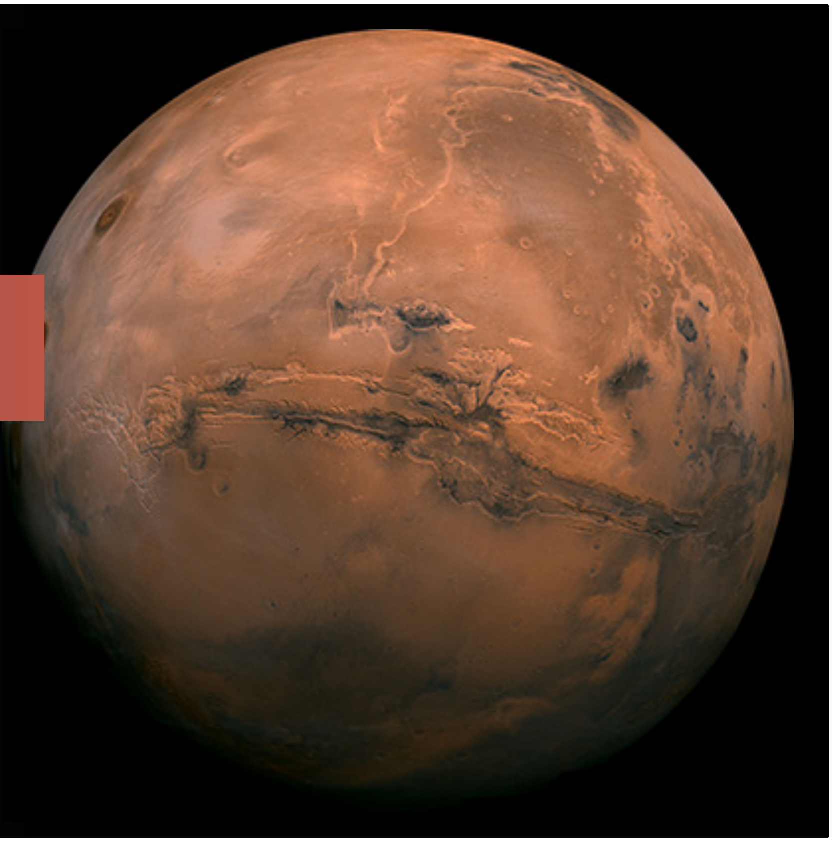
Supply chain issues continue to plague the industry post-pandemic at the part/component level, and in the cost and availability of qualified contracted labor.

- There is a shortage in manufacturing capacity and skilled/experienced personnel throughout the industry, particularly in avionics, flight software, and composite structures. These shortages make it difficult to meet commitments.
- JPL's ability to hire key personnel has been impressive, but onboarding and training adds inefficiencies.
- NASA, JPL, and ESA have accounted for higher costs and inefficiencies in plans to deal with personnel, parts and manufacturing. However, uncertainties remain, and inflation is expected to remain high.
- ESA reliance in US parts providers is an added complexity because of priorities given to procurements originating in the US.

Recommendation:

- (R20.1) Simplifying and finalizing designs and procurements are important in order to adapt to the changing market. Supply chain management should be specifically added as a responsibility to designated existing Program and Project personnel, or new positions should be added in order to address issues and to ensure critical review so surprises are minimized.

Appendix



MSR IRB-2 Detailed Schedule

Activity	May				June					July				August					September				
	30-6	7-13	14-20	21-27	28-3	4-10	11-17	18-24	25-1	2-8	9-15	16-22	23-29	30-5	6-12	13-19	20-26	27-2	2-8	3-9	10-16	17-23	24-30
IRB Kick Off			🟦																				
Plenary 1				🟦																			
IRB Sub Panels					🟨	🟨																	
Plenary 2							🟦																
IRB Sub Panels								🟨	🟦	🟨													
Plenary 3											🟦												
IRB Sub Panels												🟨	🟨										
Plenary 4														🟦									
Sub Panels/Report Draft															🟦	🟦							
Final Report																	🟦	🟦					
Report to SMD																		🟦					
Report to NASA																			🟦	🟦			
Report to Stakeholders																					🟦	🟦	🟦