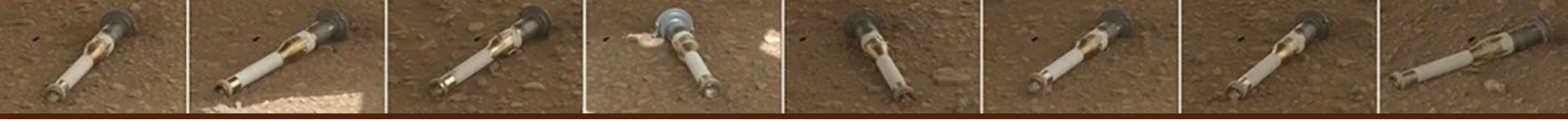

MARS SAMPLE RETURN

SAMPLE RECEIVING PROJECT (SRP)

MEASUREMENT DEFINITION TEAM 1 (MDT-1)

PRESENTATION TO
A SCIENCE STRATEGY FOR THE HUMAN EXPLORATION OF MARS: PANEL ON ASTROBIOLOGY

Heather Graham[1], Chris Herd[2]
Co-chairs
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December 4, 2024

SUMMARY

The MSR MDT has provided a comprehensive suite of analyses and associated instruments that would be carried out within the SRF, and a framework for future groups to estimate sample mass usage, operational time within the SRF, and studies to be carried out outside the SRF

Astrobiology-related objectives include habitability assessments, biosignature characterization and life detection

The MSR SRP would revolutionize our understanding of the martian surface and significantly inform approaches and potential sampling priorities for human exploration

SAMPLE RECEIVING FACILITY (SRF) MEASUREMENT PLANNING

Maximize the productivity and efficiency of the SRF

Key Question: "What is the minimum set of measurements collected within the SRF?"

- Initial Sample Characterization (ISC): Document the initial state of received samples to create and maintain a sample catalogue sufficient to allocate subsamples for investigations
- Safety: Implement the Sample Safety Assessment Protocol
- Science: Perform scientific investigations comprising time-critical properties

Drivers / Motivations / Considerations

- Technical: Assure sample safety, ensure scientific integrity, maximize science output of the samples
- Programmatic: Minimize footprint, cost, and complexity of the Sample Receiving Facility (SRF)

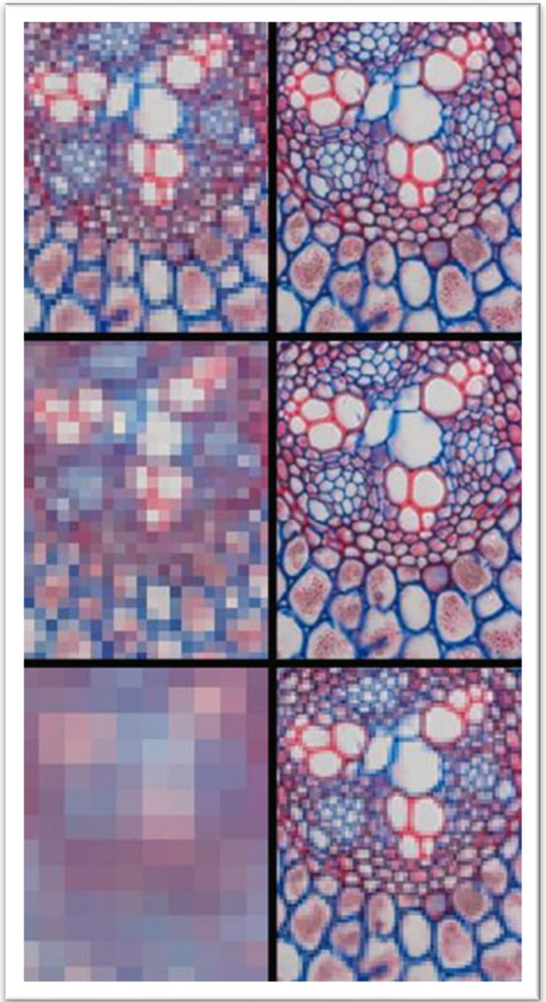
Pre-decisional. For planning and discussion purposes only.

AVOIDING MEASUREMENT / INSTRUMENT REDUNDANCIES

MDT strategically focused on minimizing the number of instruments needed

Overlapping Measurements

- High likelihood that a single measurement type may be needed to address multiple science, safety, or ISC objectives
  - e.g., microscopic imaging
- Possible that performance requirement differs depending on specific investigation
  - e.g., spatial resolution of microscopic imaging

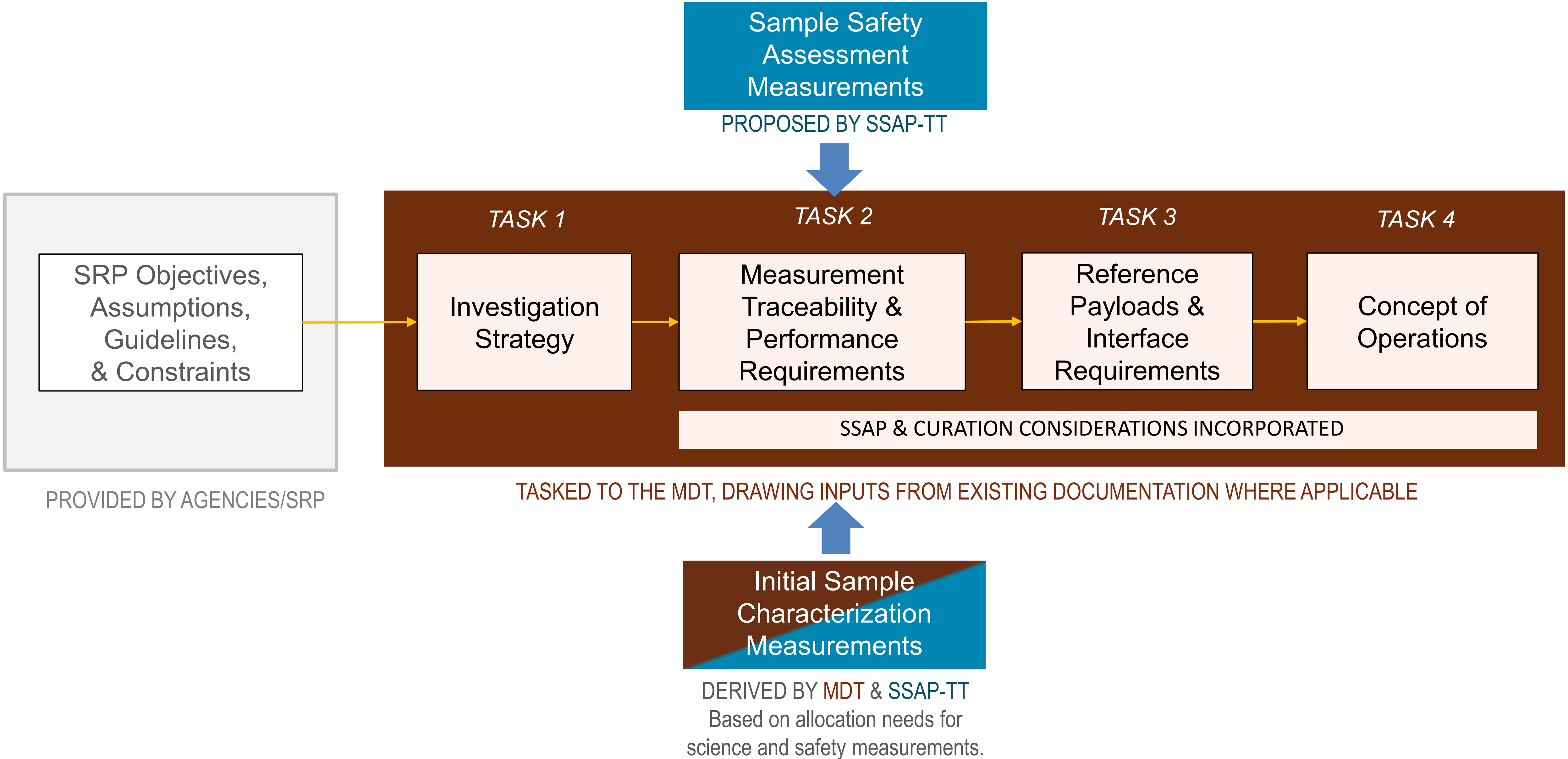


We don’t need three of the same instruments

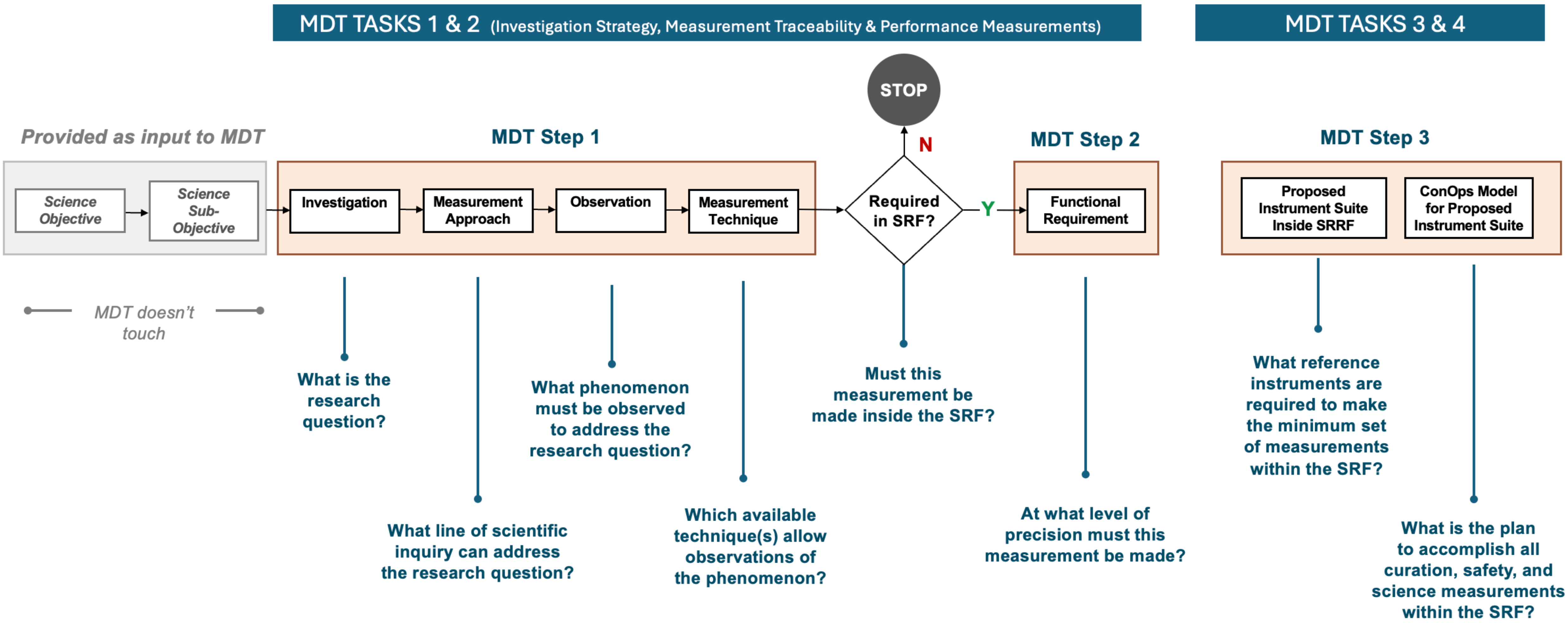
- In cases where overlapping measurements are identified, the most difficult functional requirement should be considered the baseline
  - By definition, it would then satisfy the other client(s)
  - Avoids sample waste by minimizing duplication of measurements
  - Understanding the measurement needs to address different objectives allows for optimization of SRF trade studies

Measurement Definition Team

Deriving an instrument suite and concept of operations for the SRF



MDT WORKFLOW

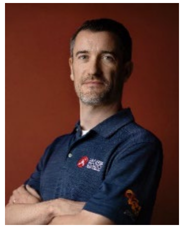


Pre-decisional. For planning and discussion purposes only.

International MDT Participants and Life Working Group Members

Co-Chairs


Heather Graham


Chris Herd

MDT Exec


Brandi Carrier


Elliot Sefton-Nash


Tim Haltigin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Bonnie Teece


Michelle Viotti

Selected Members


John Bridges


Vinciane Debaille


Jean Duprat


Marco Ferrari


Alison Fox


Kate French


Mihaela Glamoclija


Libby Hausrath


Agata Krzesinska


Yang Liu


Cara Magnabosco


Jeff Marlow


Clara Maurel


Ryan Ogliore

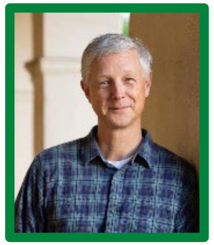

Andreas Pack


Elizabeth Rampe


Christian Schroeder


Susanne Schwenzer


Sandra Siljeström

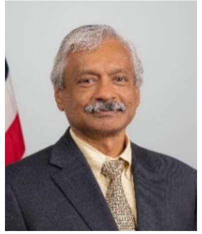

Alex Sessions

Ex Officio


Andi Harrington


Aurore Hutzler


Hannah McLaurin


Segaran Pillai


Andrew Steele


Valerie Tu

Pre-decisional. For planning and discussion purposes only.

Objectives for MSR

- The over-arching objective of the 'Life' working group was to *determine the astrobiological significance of the Martian geological record represented by the samples*
- Step-wise series of investigation sub-objectives that starts with:
  - An assessment of the past or present habitability of the site the sample represents, as well as preservation potential
  - Followed by measurements focused on elemental, mineral, or organic indications of biological influence
  - Final sub-objective focuses on evidence of active metabolism.
- Stepped approach uses information from previous measurements to guide downstream analyses. Recommended parameters for measurements were designed for the interoperability of datasets between sub-objectives and even between working groups.

Astrobiology Science Objectives

SCIENTIFIC OBJECTIVE 2.1. HABITABILITY/PRESERVATION POTENTIAL **Interpret the habitability potential of the environments recorded by the rock and atmospheric samples, as well as the extent to which potential biosignatures could have been preserved.**		
SCI 2.1.1	HISTORY & TIMING OF WATER	What was the history and timing of water (surface, groundwater, etc.) with respect to sample formation, deposition, and alteration, and does sufficient water exist presently to permit current life?
SCI 2.1.2	PHYSICAL & CHEMICAL BOUNDS ON HABITABILITY	What are the physical and chemical conditions (e.g., temperature, pH, salinity, Eh) of ancient or modern environments that show evidence of aqueous alteration or other indicators of potential habitability?
SCI 2.1.3	BIOESSENTIAL ELEMENTS	What was and is the availability and distribution of bio-essential elements, as we currently understand them?
SCI 2.1.4	CHEMICAL DISEQUILIBRIA	Is there evidence of chemical disequilibria or chemical species that could be a potential catabolic reaction pairing in Mars conditions that could serve as a source of energy for ancient or modern life?
SCI 2.1.5	ORGANICS INVENTORY	What is the total inventory of indigenous (non-contaminant) organic materials, and what factors led to their preservation or degradation?
SCI 2.1.6	ABIOTIC ORGANIC SOURCE	Which of the indigenous (non-contaminant) organic materials have an abiotic source?

Astrobiology Science Objectives

SCIENTIFIC OBJECTIVE 2.2 POTENTIAL BIOSIGNATURES **Characterize and interpret any potential biosignatures within MSR samples, identifying feasible prebiotic/biotic/abiotic mechanisms for their formation, processing, and preservation.**		
SCI 2.2.1	BIOSIGNATURE PRESERVATION	Were the environmental conditions conducive to preservation or degradation of biosignatures?
SCI 2.2.2	MARTIAN ORGANIC BIOMARKERS	Does the organic matter in the samples contain compounds, molecular patterns, or spatial distributions of organic molecules that are consistent with a Martian and biological origin?
SCI 2.2.3	ISOTOPIC PATTERNS	Do the isotopic patterns present in the detected organic materials reflect a Martian and/or biologic source?
SCI 2.2.4	ISOTOPIC INDICATORS OF LIFE	Do the samples contain isotopic variations between or within inorganic materials that might be indicative of life of Martian origin?
SCI 2.2.5	LIFE-ASSOCIATED ELEMENTAL DISTRIBUTIONS	Do the samples contain elemental distributions consistent with formation through biological processes or biological presence of Martian origin?
SCI 2.2.6	LIFE-ASSOCIATED MINERAL DISTRIBUTIONS	Do the samples contain mineral distributions consistent with formation through biological processes or biological presence of Martian origin?
SCI 2.2.7	LIFE-ASSOCIATED PHYSICAL CHARACTERISTICS	Do the samples contain structures, textures, or morphological features that could have been formed through biological processes or biological presence of Martian origin?

Astrobiology Science Objectives

SCIENTIFIC OBJECTIVE 2.3 MARTIAN LIFE Assess the possible evidence of Martian life in the MSR samples, particularly in samples determined to have the highest habitability potential.		
SCI 2.3.1	STRUCTURES OF MARTIAN ORIGIN	Do the samples contain 1) known geologically short-lived biomolecules (or molecular structures with biomolecular characteristics such as functionalization, polymerization, isomeric excesses, and electrical conductivity), or 2) cell-like structures of Martian origin that would indicate contemporary or relatively recent life based on analogy to life on Earth?
SCI 2.3.2	POTENTIAL BIOMOLECULES	Does the inventory of potential biomolecules of Martian origin display any aspect of thermodynamically improbable elemental abundances, molecules, or molecular suites – including through their spatial distributions – which, when compared against the abiotic background, would suggest involvement of a living system?
SCI 2.3.3	CHANGE OVER TIME	Does the sample change over time, with or without the addition of external stimuli, in a way that is only explainable by biological processes?

- These investigations are a subset of 88 total that were identified to achieve the science objectives of MSR
- The MDT report provides a traceability matrix for each investigations expanded into individual measurement types

Traceability Matrix Example (pg 32 of 94)

WHAT WE WANT TO KNOW				HOW WE'RE GOING TO FIND OUT				
INVESTIGATION/ RESEARCH QUESTION	JUSTIFICATION FOR INVESTIGATION / RESEARCH QUESTION	MEASUREMENT APPROACH	PROPERTY TO CONSTRAIN (Observation)	MEASUREMENT TECHNIQUE		RATIONALE FOR MEASUREMENT TECHNIQUE	TIME-SENSITIVE: REQUIRED INSIDE (Y/N)	
SCI 2.1.6 ABIOTIC ORGANIC SOURCE (Continued)			**SCI 2.1.6.2 Molecular Products** Identify molecular products (i.e., organic acids, highly oxidized macromolecules) that are commonly produced via radiolytic processes within the total inventory of organics (e.g., headspace gas, soluble organics, insoluble organics)	2.1.6.2A	GC-MS	For volatile organics in headspace gas and volatile and semi-volatile organics in extracts • To provide structural and molecular formula information	Y*	TIME-SENSITIVE MEASUREMENT MSPGS2 flagged some organics as time-sensitive, but insoluble, macromolecular organics may be less time-sensitive *Time-sensitivity could be mitigated by performing extraction and waiting to perform analysis if stored properly (e.g., dark and cold)
				2.1.6.2B	LC-MS	For polar extractable organics • To detect higher molecular weight and/or nonvolatile compounds that are not GC-amenable • To provide structural and molecular formula information	Y*	
				2.1.6.2C	Pyrolysis GC-MS	For non-extractable organics • To provide structural information • Destructive and may be influenced by mineral matrix (e.g., Royle et al., 2022)	N	

				2.1.6.2D	Solid-state NMR	• To characterize insoluble organic matter.
						  • Requires vastly more material than MS-based methods. Not a first step technique, but it potentially could be done after MS techniques if any samples are discovered that are significantly more organic-rich than expected (see notes on feasibility below).Feasibility Note:
						  • This technique would likely not be possible for several reasons. It would consume large sample amounts (likely approaching the entire core) given expected low organic content and required sample prep (demineralization). This instrument is not recommended within the SRF for several reasons: low probability that this measurement is feasible, strong magnetic field would make it challenging to house inside SRF, and not a time-sensitive measurement.
							N	

				2.1.6.2E	Raman and IR Spectroscopy	• To provide functional group information
						  • May be sensitive to mineral interference.
						  • Raman and IR have different sensitivities to different bonds (asymmetric and symmetric) such that they differ in their ability to detect different compounds classes (e.g., asymmetric and symmetric), thereby providing complimentary information to each other.
						  • Less informative for bulk measurements (non-spatial analyses) than MS techniques, so lower priority than MS techniques. But they are non-destructive and could provide complimentary information to MS-based technique
							N	

Key Astrobiology Take-aways

- Returned sedimentary samples are an opportunity to examine habitable materials that also have the greatest biosignature preservation potential.
  - MSR samples can be used to better connect phyllosilicate mineralogy with organic preservation
  - Enables analytical methods for complete characterization of high-molecular weight and polar compounds by high-resolution mass spectrometry.
- Analyses necessary within the SRF have focused on fragile hydrated mineral phases that could include important fluids or volatile organic phases likely to be lost during sample handling.
- Analyses are focused on understanding the context and stability of molecular suites in order to gauge biogenicity.
- A possible mitigation for the time-sensitive nature of many organic analytes would be the extraction and cold-storage of these concentrates. Future work will help inform this choice.

Summary of Findings: Science

What we can learn

Finding 1 The MSR SRP would revolutionize our understanding of the formation, evolution, and habitability of Mars.

Finding 2 The majority of scientific measurements could be collected outside of the SRF.

Finding 3 The Perseverance sample suite is scientifically superior to the Three Forks suite.

Finding 5 Substantial science would be lost if time-sensitive measurements are not enabled within the SRF.

Pre-decisional. For planning and discussion purposes only.

Summary of Findings: Sample Receiving Facility

What we need to learn it

Finding 4	A baseline set of 19 instruments would be needed within the SRF.
Finding 7	Some instruments within the SRF may be located outside of the biocontainment barrier.
Finding 8	Supporting infrastructure would be required within the SRF to accommodate sample preparation, handling, and analysis.
Finding 12	Investments in additional instruments may result in overall schedule and cost savings.

Instrument List

MDT significantly reduces the number of proposed SRF instruments, while meeting key ISC, SSAP, and TSS measurements

	MDT Threshold												MDT Baseline							*Not Included in MDT List*													
Instrument Type	HIGH-RESOLUTION X-RAY COMPUTED TOMOGRAPHY	STEREO OPTICAL MICROSCOPE	INFRARED SPECTROMETER	RAMAN SPECTROMETER WITH DEEP UV	EGA- MASS SPECTROMETER	LIQUID CHROMATOGRAPH MASS SPECTROMETER	GAS CHROMATOGRAPH MASS SPECTROMETER	IMAGING MOLECULAR MASS SPECTROMETER	MICRO-X-RAY FLUORESCENCE ANALYZER	FIELD EMISSION SCANNING ELECTRON MICROSCOPE	FLUX-GATE MAGNETOMETER	MAGNETIC SUSCEPTIBILITY METER	MICROBIOLOGY ASSAY SUITE4	X-RAY DIFFRACTOMETER	MÖSSBAUER - BACKSCATTER	MÖSSBAUER - TRANSMISSION	FLUORESCENCE MICROSCOPE	FLUORESCENCE SPECTROMETER[1]	ELECTRON PARAMAGNETIC RESONANCE (EPR) SPECTROSCOPY	Multi/hyperspectral Imager 400-2500nm	Petrographic Microscope	GC-IRMS (2)	VP-SEM	Cavity Ring Down or TLS	MALDI-TOF MS	Capillary Electrophoresis MS	Ion Chromatography (IC)	ICP-OES	X-ray pair distribution (PDF)	Brunauer-Emmett-Teller (BET) surface area analysis	SIFT or PTR-MS	ESI-MS	**Total Instruments in SRF**
MDT (ISC)	•	•	•	•	•	•			•	•	•	•			• *																		18
MDT (SSAP)	§	§	§	§	§	§	§	§																									
MDT (TSS)	◷	◷	◷	◷	◷	◷	◷	◷	◷	◷	◷	◷	◷	◷	◷	◷	◷	◷	◷														
MSPG2 (2022)	✓	✓	✓	✓		✓	✓		✓	✓	✓	✓	✓	✓			✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	28
MCSG (2023)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓					✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			27

Proposed instruments for the Sample Receiving Facility

- *Backscatter Mössbauer is not on the baseline list because it is only needed for ISC-related, time-sensitive measurements
- [1]Fluorescence spectrophotometer would also be part of the microbiology assay suite. If the microbiology assay suite is not implemented the fluorescence spectrophotometer would still be needed for other time-sensitive science

Summary of Findings: Concept of Operations

Optimizing analyses to facilitate learning

Finding 9	A well-designed sample analysis plan would minimize sample usage and processing time.
Finding 10	The total sample mass to be analyzed within the SRF would be highly dependent on the concentration of the feature of interest.
Finding 11	The time to collect sequential measurements on a given subsample is only a small portion of the total analysis time.

Conceptual Model for Sample Processing for a TSS Investigation

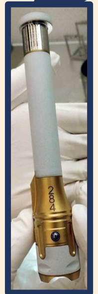
MARS

Uganik Island abrasion patch (5 cm across) and associated ***Kukaklek* sample** (inset; 1.3 cm across); shown to scale.

- The 49.7 mm sample is onboard Perseverance.
- The sample is a fine to medium sandstone with both siliciclastic and sulfate grains, and multiple generations of sulfate cement.
- Minerals identified by rover instruments include phyllosilicates, anhydrite, hydrated Fe-Mg sulfates, hematite, possible chlorides, and ferric sulfate.

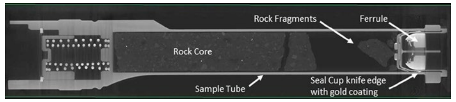
MSR →

INSIDE BIOCONTAINMENT IN THE SRF



Unopened Tube – Safety, Science, and Initial Characterization

XCT — *mins*



→ **MAGNETOMETRY** — *mins*

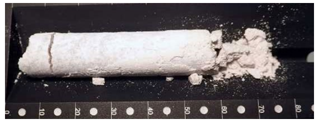
↓ ***Opening of tube, including capture of headspace gas***

Extruded Core – Initial Characterization

Enables subsample selection for investigation 2.1.1.2 (i.e., enriched in hydrated minerals).

Yields identification and distribution of minerals and compositional variation.

OPTICAL MICROSCOPY — *mins*



MAGNETOMETRY — *hours* → **BACK-SCATTERED MÖSSBAUER** — *mins* → **REFLECTANCE IR** — *mins* → **RAMAN/ DUV** — *hrs* → **µXRF** — *hrs*

↓ ***Selection and removal of subsample*** ⇨

Subsample(s) – Conceptual Example of Time-sensitive Science Investigation (MTM 2.1.1.2)

Achieves Observation: Mineralogy, including hydrated minerals and hydration state.

~100 mg

CHIPS/GRAINS

OPTICAL MICROSCOPY — *mins* → **RAMAN** — *mins* → Powder Prep — *mins*

~50 mg

POWDER

OPTICAL MICROSCOPY — *mins* → Sub-sampling — *mins* → **XRD** — *mins* — *~20 mg*; **RAMAN** — *mins* — *~few mg* → **FTIR** — *mins* — *~few mg*

TOTAL TIME*
<1 day

TOTAL MASS PROCESSED:
~100 mg

*Times do not include time for instrument calibration or contamination knowledge and control.

Conceptual Example of Sample Processing for a Specific Time-sensitive Science Investigation (MTM 2.1.1.2)

Pre-decisional. For planning and discussion purposes only.

SUMMARY

The MSR MDT has provided a comprehensive suite of analyses and associated instruments that would be carried out within the SRF, and a framework for future groups to estimate sample mass usage, operational time within the SRF, and studies to be carried out outside the SRF

Astrobiology-related objectives include habitability assessments, biosignature characterization and life detection

The MSR SRP would revolutionize our understanding of the martian surface and significantly inform approaches and potential sampling priorities for human exploration

Back Up

Next Steps

Aim to provide full list of instrumentation required within the SRF

➢ Future MDTs / SDTs could be anticipated

What can future group(s) advance?

- Outline a coordinated program of Research and Development
- Establish a systems approach to elaborate the Concept of Operations, including sample mass estimates and required processing times
- Define performance requirements, instrumentation, and concept of operations for scientific investigations to be conducted outside of the SRF

Pre-decisional. For planning and discussion purposes only.

Report Finalization

Near Term

- MDT Exec is currently reviewing feedback from the Independent Assessment Team
- MDT will respond to and integrate feedback, discuss any outstanding issues, and produce the final draft in ~6 weeks

Potential Follow-up

- Report out to MEPAG at Fall virtual meeting
- Community workshop to review draft scientific objectives and potential missing investigations
  - Feed forward into final science objectives to enter approval process
  - New/revised objectives & associated investigations could flow into MDT-2 for incorporation into the next version of the MTM
- Draft Terms of Reference for MDT follow-on group

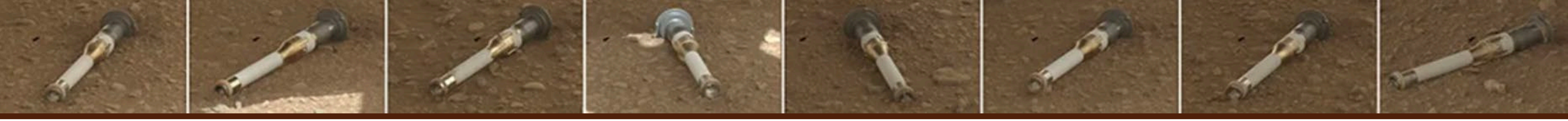
SUMMARY

The MSR SRP would revolutionize our understanding of the formation, evolution, and habitability of Mars, and would be best served by returning the samples on board *Perseverance*

The baseline set of instruments in the SRF is 17 instruments [TBC], ~33% smaller than previous estimates (MSPG2, MCSG)

MDT results provide an important framework for future groups to estimate sample mass usage and operational time within the SRF

Pre-decisional. For planning and discussion purposes only.



MARS SAMPLE RETURN

SAMPLE RECEIVING PROJECT (SRP)

MEASUREMENT DEFINITION TEAM 1 (MDT-1)

Co-Chairs: Heather Graham[1], Chris Herd[2]

Study Leads: Brandi Carrier[3], Elliot Sefton-Nash[4]

Exec. Committee Members: Tim Haltigin[5], Michelle Viotti[3], Daniel Paardekooper[6], Bonnie Teece[4]

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