International Mars Architecture for the Return of Samples (iMARS) Phase II: Findings and Recommendations

Caroline Smith, Tim Haltigin and the iMARS Phase II Working Group
1. Introduction
• **International Mars Architecture for the Return of Samples**

• Originally chartered by IMEWG in 2006 to develop a plan for Mars Sample Return Mission Architecture

  – **IMEWG: International Mars Exploration Working Group**
“2 + 1” approach highlights the importance of the post-return segment → ground operations are integral part of the mission
iMARS Phase I – Recommendations

“IMSI” Concept

- Multinational mission will require multinational coordination to accomplish
  - Need to define an International MSR Science Institute

Distributed vs. On Site Needs

- Not everyone with an excellent science investigation would be able to work at the return facility
  - How do we keep the samples from becoming “stuck in containment?”
“Propose a baseline implementation approach for MSR... identify[ing] critical challenges and opportunities.”
“The science team will presuppose successful identification and collection of a set of samples ... [and] ... develop the framework of a sample science management plan.”
Roster

Steering Committee

- NASA
- Lisa May → Dave Lavery
- Rolf de Groot
- Lev Zelenyi
2. MSR Status and Assumptions
## E2E-iSAG MSR Objectives (2011)

<table>
<thead>
<tr>
<th>Priority</th>
<th>Reference #</th>
<th>Objective Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A1</td>
<td>Critically assess any evidence for past life or its chemical precursors, and place detailed constraints on the past habitability and the potential for preservation of the signs of life.</td>
</tr>
<tr>
<td>2</td>
<td>C1</td>
<td>Quantitatively constrain the age, context and processes of accretion, early differentiation and magmatic and magnetic history of Mars.</td>
</tr>
<tr>
<td>3</td>
<td>B1</td>
<td>Reconstruct the history of surface and near-surface processes involving water.</td>
</tr>
<tr>
<td>4</td>
<td>B2</td>
<td>Constrain the magnitude, nature, timing, and origin of past planet-wide climate change.</td>
</tr>
<tr>
<td>5</td>
<td>D1</td>
<td>Assess potential environmental hazards to future human exploration.</td>
</tr>
<tr>
<td>6</td>
<td>B3</td>
<td>Assess the history and significance of surface modifying processes, including, but not limited to: impact, photochemical, volcanic, and aeolian.</td>
</tr>
<tr>
<td>7</td>
<td>C2</td>
<td>Constrain the origin and evolution of the martian atmosphere, accounting for its elemental and isotopic composition with all inert species.</td>
</tr>
<tr>
<td>8</td>
<td>D2</td>
<td>Evaluate potential critical resources for future human explorers.</td>
</tr>
<tr>
<td>ADDITIONAL</td>
<td>A2</td>
<td>Determine if the surface and near-surface materials contain evidence of extant life.</td>
</tr>
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## Advances Since 2008

<table>
<thead>
<tr>
<th>Technology</th>
<th>Mission</th>
<th>Applicability to MSR</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Guided entry into Mars atmosphere</strong></td>
<td>Mars Science Laboratory (NASA)</td>
<td>The spacecraft’s descent into the martian atmosphere was guided by small rockets on its way to the surface, controlling the spacecraft’s descent until the rover separated from its final delivery system, the sky crane. This landing technique allows landing larger and more capable rovers carrying more science instruments.</td>
</tr>
<tr>
<td><strong>Sky crane terminal descent</strong></td>
<td>Mars Science Laboratory (NASA)</td>
<td>With spacecraft velocity close to zero, the sky crane lowered the rover to the surface from the descent stage. At touchdown, the descent stage separated from the lander and flew away, allowing the landed system to begin its mission.</td>
</tr>
<tr>
<td><strong>Multi-Mission Radioisotope Thermoelectric Generator (MMRTG) for rovers</strong></td>
<td>Mars Science Laboratory (NASA)</td>
<td>MMRTGs are a new generation of long-lived, reliable nuclear power systems ideally suited for missions involving autonomous operations in the extreme environments of space and on planetary surfaces. They reliably convert heat into electricity, generate power in increments (100+ Watt), optimize lifetime power levels (14+ years), minimize weight and ensure a high degree of safety.</td>
</tr>
<tr>
<td><strong>Drilling</strong></td>
<td>Mars Science Laboratory (NASA)</td>
<td>MSL’s Powder Acquisition Drill System can acquire powdered rock samples from up to 5 cm inside the surface of a rock. This system is part of the Sample Acquisition, Processing and Handling subsystem. Philae’s Sample Drill and Distribution system includes an integrated drill, sampler tool, and a carousel designed to collect soil samples at depths of up to 230 mm.</td>
</tr>
<tr>
<td><strong>Asteroid sample return (EVE)</strong></td>
<td>Hayabusa (Japan)</td>
<td>Entry capsule with a container designed to carry samples from the asteroid to Earth and enter the atmosphere at a velocity of up to 12 km/s.</td>
</tr>
<tr>
<td><strong>Hayabusa</strong></td>
<td>JAXA</td>
<td>Hayabusa performed “touch-and-go” landing on asteroid Itokawa.</td>
</tr>
</tbody>
</table>
Lessons From Previous Sample Return Missions

**Storage / Quarantine / Curation**
- No quarantine or planetary protection since Apollo

**Preliminary Examination**
- Detailed investigation flow based on sample suite

**Sample Return Facility**
- Sets expectation for level of technology found behind containment

**Technical Support**
- Staffing and institutional needs
Planetary Protection Considerations

- MSR campaign will not be optimized for extant life detection
- Returned samples must still be treated as though they may contain life
- Need to balance desires of science community with planetary protection requirements
3. MSR Campaign Architecture and Implementation
Focus Areas (Engineering)

“Propose a baseline implementation approach for MSR... identifying critical challenges and opportunities.”

<table>
<thead>
<tr>
<th>(1) IMPLEMENTATION</th>
<th>(2) TECHNOLOGIES</th>
</tr>
</thead>
<tbody>
<tr>
<td>• What is the overall campaign architecture?</td>
<td>• What technologies are required to implement it?</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>(3) TIMELINE</th>
<th>(4) CAMPAIGN MANAGEMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>• When can it be implemented?</td>
<td>• How can it be coordinated?</td>
</tr>
</tbody>
</table>
• **CR-1**
  - MSR shall collect samples of rock, granular materials (regolith, dust) from various regions of scientific interest, and atmospheric gas.

• **CR-2**
  - MSR shall collect in-situ information for sample selection and establishment of its geological context.

• **CR-3**
  - MSR shall return to Earth a minimum of 500 g sample mass.

• **CR-4**
  - MSR shall maintain the scientific integrity of samples from collection on Mars through containment on Earth.

• **CR-5**
  - All MSR flight and ground elements shall meet planetary protection requirements for Category V, restricted Earth return, established by COSPAR (see Appendix 6.2).
Mars Sample Return Reference Architecture (3+1)
Sample Caching Rover (SCR) element:

- Earth-Mars cruise stage
- Entry-descent-landing (EDL) system
- Mobile rover with a science & sampling payload
- Cache transfer assembly (CTA)
Sample Retrieval & Launch (SRL) element:

- Earth-Mars cruise stage
- EDL system
- Sample retrieval system
- Mars ascent vehicle (MAV)
- Orbiting Sample container (OS)
Sample Return Orbiter (SRO) element:

- Orbiter with a rendezvous sensor suite and a capture mechanism
- Bio-Containment system
- Earth Re-entry Capsule (ERC)
- Propulsion module

Sample handling & biosealing

Re-entry capsule

ERC hard landing
Notional Campaign Timeline (2031 Sample Return)

Sample Caching Rover Mission
- Pre-A: MCR
- Phase A: SRR
- Phase B: CDR
- Operation: Launch, Landing
- N/A: 7/20, 2/21, 2/23, 11/17, 11/19

Sample Return Orbiter Mission
- Pre-A: MCR
- Phase A: SRR
- Phase B: CDR
- Operation: Launch, Arrival/MOI, Rendezvous, Earth Entry
- N/A: 9/24, 9/25, 11/30, 9/31

Sample Retrieval and Launch Mission
- Pre-A: MCR
- Phase A: SRR
- Phase B: PDR
- Operation: Launch, Landing
- N/A: 8/23, 8/24, 8/25, 1/27

Mars Returned Sample Handling Facility
- Planning and Requirements: Sight Selection and Design
- Design: PDR
- Build and Commission: Certification
- Exercise: Samples Returned
- Operations: 9/31

Additional Notes:
- 11 month Surface Operations
- 11 month Surface Operations
- 11 month Surface Operations
**Major challenge:** Must combine elements of positive- and negative-pressure environments

Rummel et al. (2002)
SRF Design Considerations

- Sample Suite Protocols
- Planetary Protection Protocols
- Financial Resources
- Council Mandate
- Facility Location
- BSL4/Cleanlab Expertise
- Curation Input
- Local Considerations

Major size driver
## SRF: Development Timeline

<table>
<thead>
<tr>
<th>YEAR</th>
<th>EVENTS</th>
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</thead>
<tbody>
<tr>
<td>Year X:</td>
<td>Funding is in place; negotiate staffing of Institute Council and initiate searches for SAB, BCB, and PAB members</td>
</tr>
<tr>
<td>Year X+1:</td>
<td>Executive positions (Institute Council, SAB, BCB, and PAB) in place; initiate search for Facility Director</td>
</tr>
<tr>
<td>Year X+1.5:</td>
<td>Facility Director in place; initiate searches for Science, Curation and Safety Heads</td>
</tr>
<tr>
<td>Year X+2:</td>
<td>Leadership team in place; initiate searches for key personnel required for SRF design (multiple positions)</td>
</tr>
<tr>
<td>Year X+3:</td>
<td>Begin design of SRF, including preparation of draft protocols for preliminary examination of samples, needed to design facility (allow two years based on Lunar Receiving Laboratory experience). Site selection process commences for the SRF</td>
</tr>
<tr>
<td>Year X+5:</td>
<td>SRF design in place</td>
</tr>
<tr>
<td>Year X+6:</td>
<td>Begin SRF construction (allow two years, based on BSL-4 experience, but may be less or more)</td>
</tr>
<tr>
<td>Year X+8:</td>
<td>Begin SRF analytical laboratories construction (allow one year); begin analytical instrument selection process (this should be left as late as possible to ensure cutting edge facility)</td>
</tr>
<tr>
<td>Year X+9:</td>
<td>Install and carry out specifications testing on laboratory instrumentation</td>
</tr>
<tr>
<td>Year X+9.5:</td>
<td>Carry out verification and validation of facility and laboratories</td>
</tr>
<tr>
<td>Year X+10:</td>
<td>SRF completed and “ready” to receive samples; carry out operational readiness testing</td>
</tr>
<tr>
<td>Year X+12:</td>
<td>Mars samples delivered to SRF</td>
</tr>
</tbody>
</table>
4. Sample Science Management Plan
Assuming we are returning samples safely from Mars, how are we going to deal with them when we get them back?

(1) ORGANIZATION
- Outlines general institute structure and needs for facilities

(2) SCIENCE MANAGEMENT
- Defines scientific leadership, institute membership and funding

(3) SCIENCE OPERATIONS & DATA
- Sets plan for sample access and scientific investigation

(4) CURATION PLAN
- Focuses on sample handling, storage, and distribution
Assuming we are returning samples safely from Mars, how are we going to deal with them when we get them back?

**Focus Areas**

1. **Organization**
   - Outlines general institute structure and needs for facilities.

2. **Science Management**
   - Defines scientific leadership, institute membership, and funding.

3. **Science Operations & Data**
   - Sets plan for sample access and scientific investigation.

4. **Curation Plan**
   - Focuses on sample handling, storage, and distribution.

How is the organization structured and managed?

What are its key functions?
Assuming we are returning samples safely from Mars, how are we going to deal with them when we get them back?

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Proposed Organizational Structure
Proposed Organizational Structure

**Key Stakeholders**: agency / government representation

**Oversight**: independent bodies

**On-Site Technical Branches**: institute employees

**Distributed Institute Teams**: international experts
Proposed Organizational Structure

- Board of Directors
- Audit Committees
- Employees
- Consultants
## Opportunities for Science Participation

<table>
<thead>
<tr>
<th>Potential Role</th>
<th>Sample Collection</th>
<th>Post-Collection / Pre-Return</th>
<th>Preliminary Examination</th>
<th>On-Site Investigations</th>
<th>Off-Site Investigations</th>
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<tbody>
<tr>
<td></td>
<td>Sample team</td>
<td>Suite-based virtual team</td>
<td>Mars Sample Preliminary Examination Team (MSPET)</td>
<td>Guest scientist</td>
<td>External scientist</td>
</tr>
<tr>
<td>Location</td>
<td>Distributed</td>
<td>Distributed</td>
<td>At SRF</td>
<td>At SRF</td>
<td>Distributed</td>
</tr>
<tr>
<td>Selection Process</td>
<td>Competed</td>
<td>Competed</td>
<td>Competed &amp; appointed</td>
<td>Competed</td>
<td>Competed</td>
</tr>
<tr>
<td>Activities</td>
<td>Select which samples are collected</td>
<td>Develop sample analysis and handling protocols</td>
<td>Conduct initial physical and geochemical characterization</td>
<td>Perform hypothesis-driven research within the SRF</td>
<td>Perform hypothesis-driven research at home institution</td>
</tr>
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**Objective:** Ensure that there are several “entry points” for community members to become participants in the process
## Focus Areas

**Assuming we are returning samples safely from Mars, how are we going to deal with them when we get them back?**

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Initial analysis will follow a pre-designated and peer-reviewed protocol
   • *this should be our starting place*

BSL-4 unlike most others – *no bugs out OR in*
   • best model may be forensic science facilities

SCF instrumentation chosen ≥2 years in advance limiting ability to carry out state-of-the-art preliminary examination
   • Adaptability of facility design/infrastructure will be very important

Preliminary analyses carried out in SCF will need to satisfy both Planetary Protection and Science needs
   • PP and preliminary science investigations are highly complementary and inform each other
Preliminary Sample Analysis (General Flow)

- Conducted within containment at SCF; initially protocol-dominated
- SCF staff-dominated (MSPET), with some incorporation of Guest / External scientists
Preliminary Sample Analysis (Detailed Flow)
Sample Allocation Assessment: a two-stage process

- **Stage 1 – Sample Availability Determination**
  - Enquiries about sample availability – review focuses on availability, lab verification and validation, management plan, consistency with published sample strategy plan, etc.

- **Stage 2 – Formal Sample Request**
  - formal requests with evidence of funding, and peer review, updates from enquiry, etc. – review focuses on consistency with initial enquiry, changed circumstances, etc. – philosophy is that if all thing went according to plan, samples will be made available

Sample Allocation Structure

- **Sample Allocation Committees (SAC)**
  - one for each sample “suite” (e.g., SAC-Ign, SAC-Sed, etc.) – approves normal requests – composed of Discipline Curator, Discipline Staff Scientist, Specialist scientists

- **Sample Allocation Review Board (SARB)**
  - deal with appeals, special requests – composed of Curator, Science Director, Outside scientists
Increased Complexity of Sample Curation

EG. Apollo Samples

<table>
<thead>
<tr>
<th>Within Facility?</th>
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<tbody>
<tr>
<td>Yes</td>
</tr>
<tr>
<td>No</td>
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</table>

Will require dedicated, permanent curatorial staff

Mars Samples

<table>
<thead>
<tr>
<th>Within Facility?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
</tr>
<tr>
<td>No</td>
</tr>
</tbody>
</table>

Within Containment?

<table>
<thead>
<tr>
<th>Yes</th>
<th>No</th>
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<tbody>
<tr>
<td>No</td>
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</table>
Sample Tracking and Routing

Samples will need to be tracked within, leaving, and re-entering the SCF

- Curation and tracking of “destroyed” or “altered” samples
- Avoidance of sample cross-contamination
- “Waste” samples still have scientific value
- Complexity of sub-sample multiplication
  - One sample goes out → TBD number of samples are returned
  - Samples are returned in non-original state, have been studied at different labs etc.
- Ensuring external laboratories maintain sample handling and curatorial protocols e.g. cleanliness, documentation

We have developed a high-level routing protocol for samples going OUT of the SCF and returning IN to the SCF
Sterilization Techniques

Assumption that samples are hazardous

• Until proven to be non-hazardous, samples must be rendered safe by some sterilisation method in order to be released from containment

Two key issues need to be addressed

• 1) what technique(s) should be used?
• 2) which samples/how much sample should be sterilised?

Some previous work has been carried out in this area → investigation of gamma-ray effects on rock, minerals (Allen et al. JGR, 1999)

• Unclear how $\gamma$-ray sterilisation could affect key science objectives e.g. analyses of organics, isotope geochemistry
• Other sterilisation methods are available, all have advantages and disadvantages
• Techniques for sterilisation of samples is a key issue and requires further attention
• Important implications for SCF requirements going forward
iMARS Phase I recommendation of 40 % ‘archive’ sample remains valid

- Which 40 % is chosen is an open topic
  - 40% of everything?, 40 % of certain samples?
- Archive sampling recommendations will be defined before and during sample acquisition and preliminary investigation
- Should some samples remained unopened (‘pristine’)?
  - As above → which, how many?
  - ‘Blank’ samples will be important in this context
5. Conclusions and Recommendations
Summary & Conclusions

Programmatics

- MSR requires extensive international collaboration
- Successful partnership relies on early and binding long-term commitments

Technology

- 10+ years from conception to operational readiness
- 3+1 architecture provides flexibility in responsibilities and failure mitigation

Sample Management

- Science, safety, and curation must be considered together
- Key requirements and protocols require formal definition
Key Recommendations

1. **Planetary Protection Protocol**
   - should be produced as soon as possible
   - international task force should be created

2. **Sterilization Protocol**
   - methods and doses required to adequately sterilise samples returned from Mars must be defined
   - international working group should be tasked, or individual agencies should fund extensive research

3. **Institute and SRF require 12 year lead time**
   - stepwise development will be required

4. **MAV and “Break-the-Chain” require focused development**
   - technology has advanced significantly, but still a few steps to go...