Mars Sample Return Planning - Strategies for Meeting Planetary Protection Requirements

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NASA Johnson Space Center

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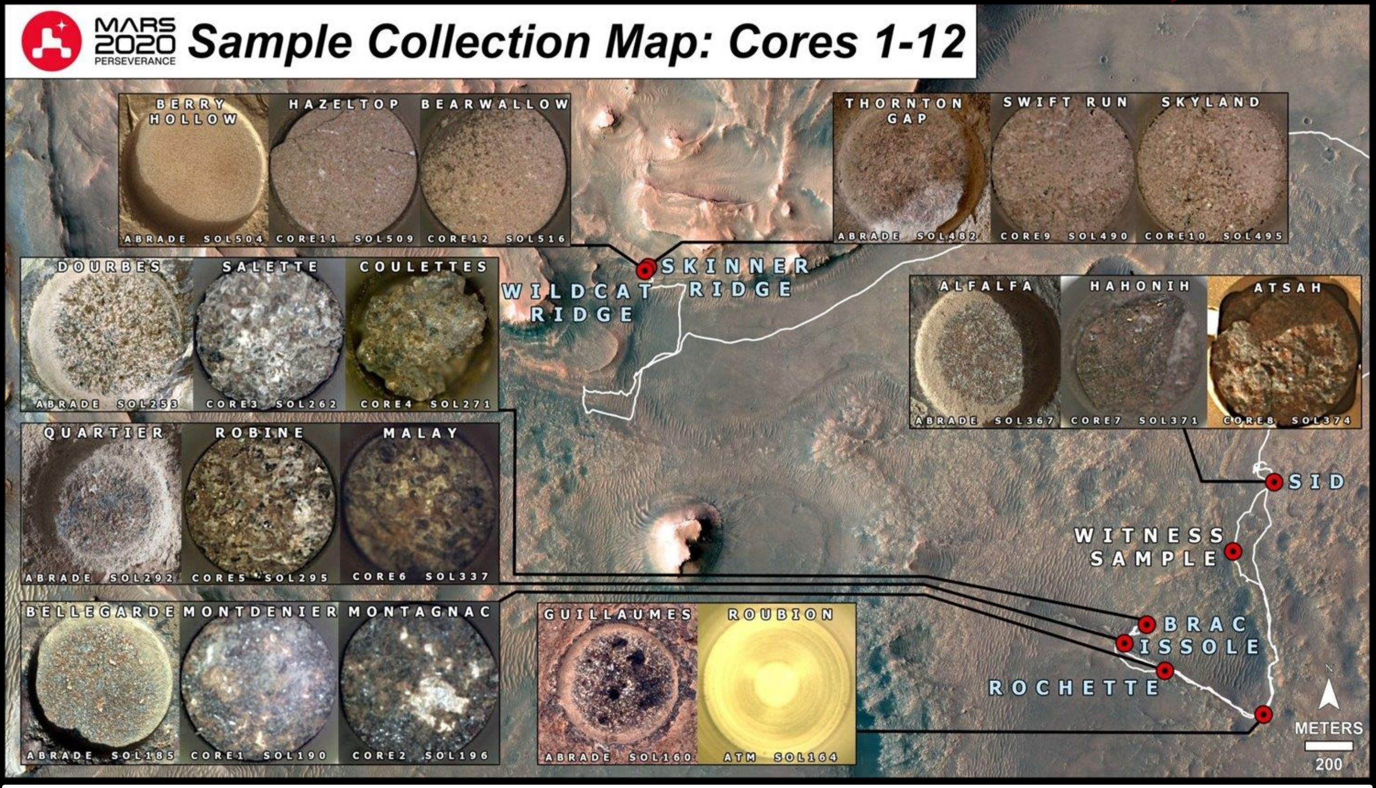
Astromaterials Research and Exploration Scien
Johnson Space Center

The decision to implement Mars Sample Return will not be finalized until NASA's completion of the National Environmental Policy Act (NEPA) process. This document is being made available for information purposes only.

INTRODUCTION

- Mars Sample Return (MSR) is a strategic partnership between NASA and ESA.
- The Campaign would notionally return between 10-26 geologically diverse samples (plus witness tubes) with the ability to answer an array of science objectives.
- One of the high priority science objectives is to "assess and interpret the potential biological history of Jezero Crater, including assessing returned samples for the evidence of life." (iMOST Report)




First samples from Delta Front Campaign

Planetary Protection Guidelines

- In compliance with the UN Treaty on Principles Governing the Activities of States in the exploration and Use of Outer Space, the COSPAR Policy on Planetary Protection (PP) has designated Mars Sample Return (MSR) as a Planetary Protection Category V, restricted Earth return due to the scientific opinion that Mars is of significant interest to the process of chemical evolution and/or the origin of life.
  – Article IX of the UN Space Treaty […] states: "parties to the Treaty shall […]conduct exploration of [Mars] so as to avoid […] harmful contamination and also adverse changes in the environment of the Earth resulting from the introduction of extraterrestrial matter and, where necessary, shall adopt appropriate measures for this purpose.

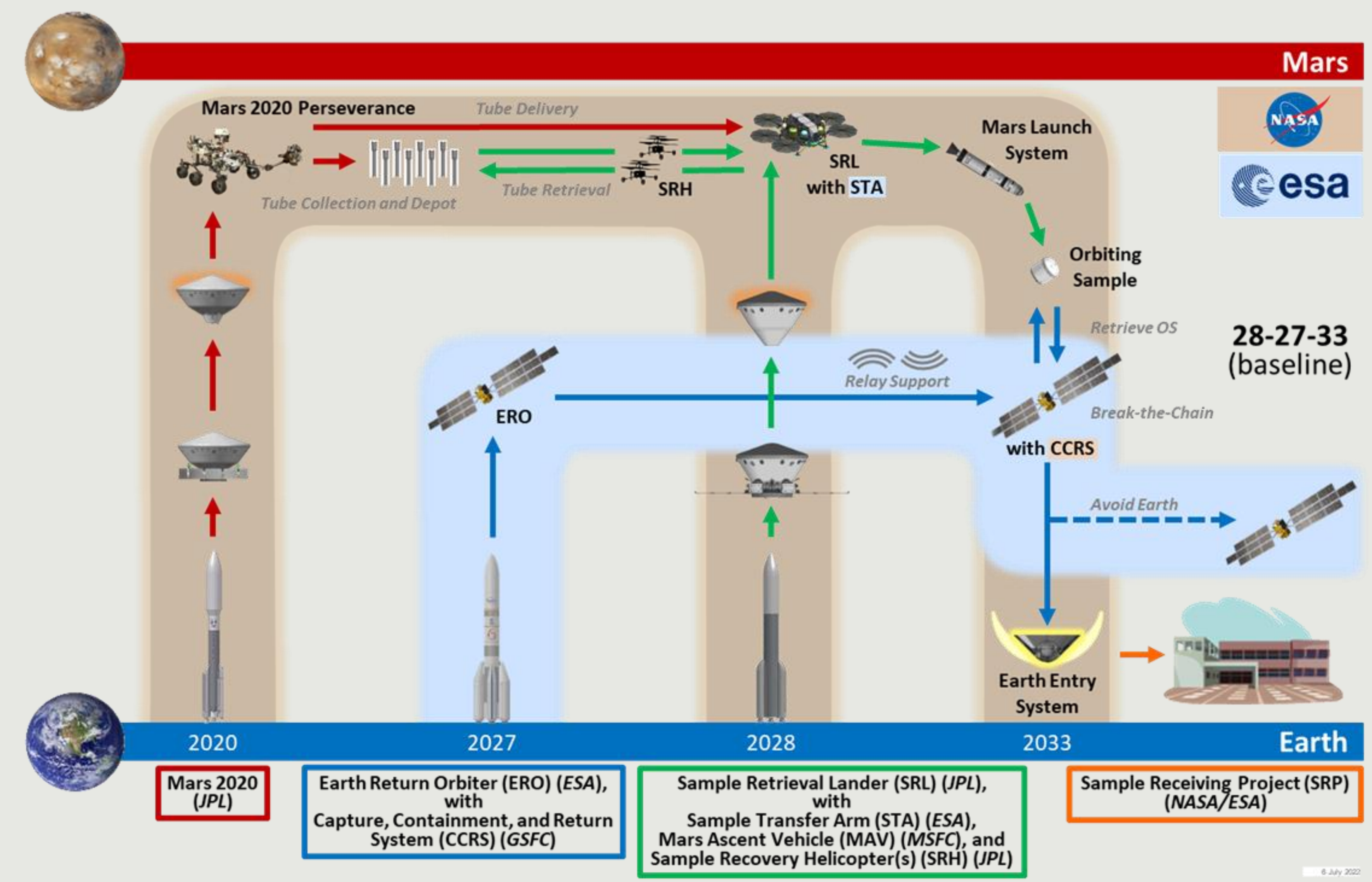
- NASA Standard for Implementing PP Requirements for Space Flight (NASA-STD-8719.27, August 2022)
  – § 5.4.3 Category V(r) missions shall demonstrate avoidance of harmful contamination of the Earth by release of one or more unsterilized particles of extraterrestrial material during all mission phases on Earth leveraging one or more of the following approaches:
    - Containment upon Earth entry [through] curation and sample safety assessment activities [via]biocontainment facility in accordance with biosafety best practices and the highest level of biocontainment)
    - Samples […] shall undergo a sample safety assessment demonstrating the sample is not harmful prior to unrestricted sample release.
    - Sample sterilization shall use a process that focusing on terrestrial degradation mechanisms occurring at a molecular level sufficient to inactivate terrestrial bioactive molecules present with a high degree of assurance prior to unrestricted sample release.
  – § 5.4.4 Missions conducting life detection investigations or sample safety assessments shall include strategies to avoid "false positives" and "false negatives" signals.

Backward PP Concern: Mars Material Hazard Potential

- Mars has very low likelihood of hosting active biology or biomolecules
  - High radiation, low water environment damages biomolecules
  - Temperature and water activity are below levels required for active metabolism at depths from which M2020 will sample
  - Absent active metabolism, biomolecules will be degraded significantly
- The biological potential of an assumed "Mars biosphere" is low
  - Cellular abundance estimates used by NASEM for the JAXA MMX mission are <10% of mean Earth abundance
  - Estimates based on available energy for metabolism indicate Mars could only host 0.01-0.001% of Earth's biomass (Sholes et al., https://doi.org/10.1089/ast.2018.1835)
- The potential hazards are also very low likelihood
  - Host-pathogen relationships are evolutionary in nature and Mars-Earth exchange is infrequent – any pathogens are likely be non-specific to Earth species (including humans)
  - Invasive (Mars) species would encounter a largely inhospitable environment
  - Meteoritic inputs have delivered Mars material throughout Earth's history – some on fast paths that do not experience sterilization (e.g., Gladman, 1997)

Still, due to our lack of data, we cannot exclude the potential for adverse effects
—and—
Current best practice is a "safety first" approach to contain unsterilized Mars material

MSR Campaign Planning Overview



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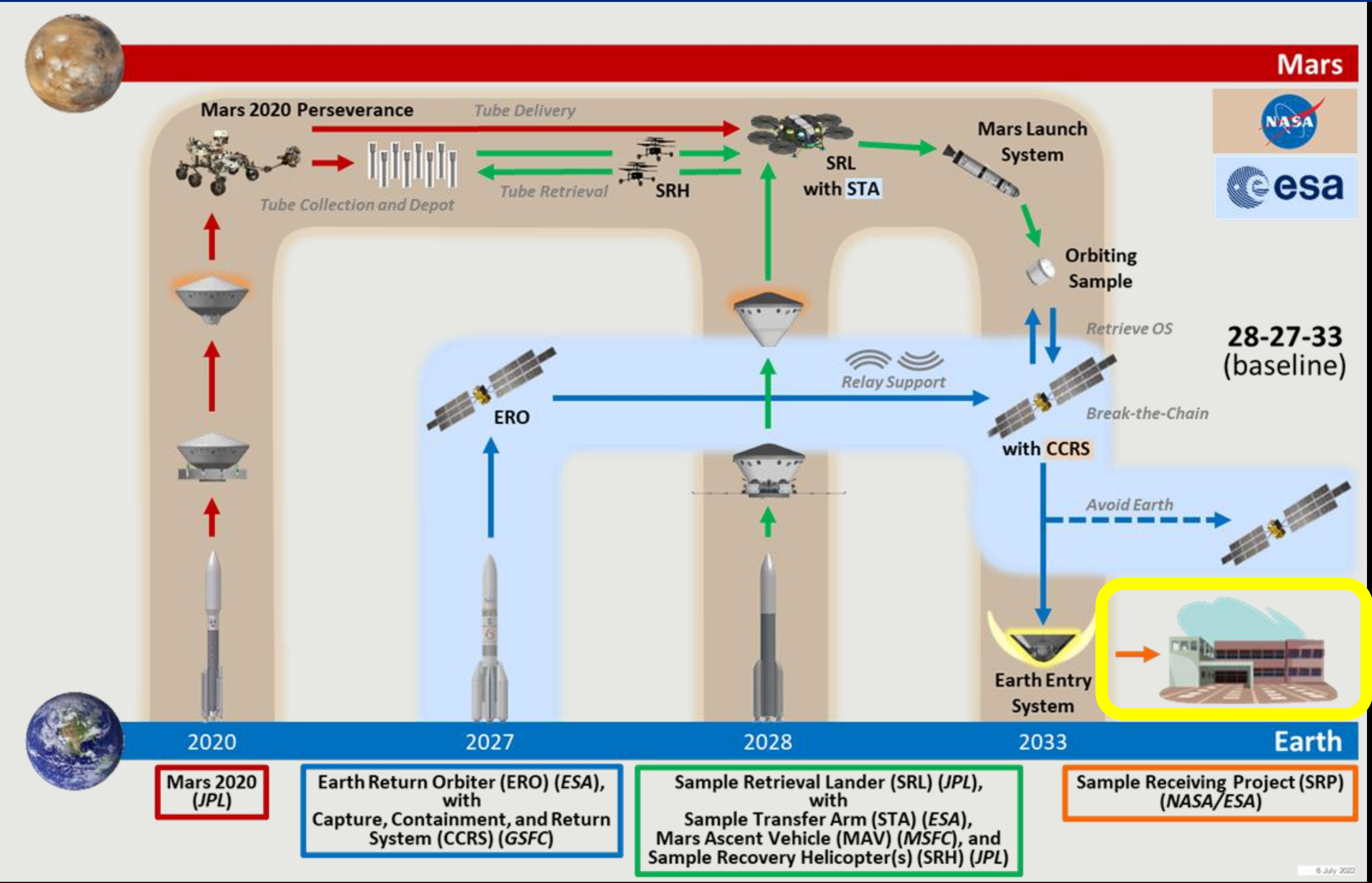


NASA Astromaterials Acquisition & Curation Office

- The Astromaterials Acquisition and Curation Office at NASA Johnson Space Center (JSC) is charged with "the curation of all extraterrestrial materials under NASA control, including future NASA missions" as per NASA Policy Directive (NPD) 7100.10F + derivative NPR "Curation of Extraterrestrial Materials."

- The Directive goes on to define Curation as including "…documentation, preservation, preparation, and distribution of samples for research, education, and public outreach."
  - As a part of documentation and preservation, the Curation Office also coordinates sample capture, containment, and transportation to the curation facility.

- A major part of the Curation Office's charge is to integrate requirements, develop implementation strategies, and deliver a facility capable of meeting Mission goals while satisfying requirements levied by the Project, Planetary Protection, the Agency, and Regulatory Authorities.
  - The Curation Office does NOT generate Planetary Protection requirements.

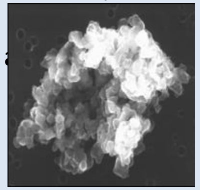
- Proper curation enables science.
  - Objective-Driven & Opportunity Science – Characterize and allocate samples in order to accomplish Project science goals and early science.
  - Future Science – Conserve a representative quantity of pristine samples for future generations of scientists with innovative ideas and more advanced analytical equipment.

JSC's Astromaterials Acquisition & Curation Office

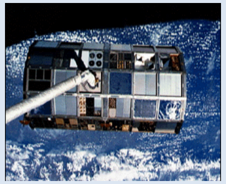
Lunar
(1969)
Apollo program lunar rocks and soils; Luna samples

Meteorite
(1977)
Antarctic Search for Meteorites (ANSMET) program

Cosmic Dust
(1981)
Cosmic dust grains from Earth's stratosphere



Microparticle Impact Col.
(1985)
Space exposed hardware from spacecraft



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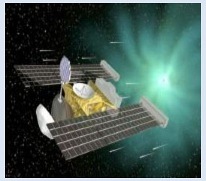
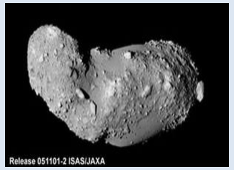
Genesis solar wind samples at Earth-Sun L1 point

Stardust
(2006)
Cometary and interstellar samples from Comet Wild 2



Hayabusa
(2012)
Samples collected from JAXA asteroid mission to Itokawa



Hayabusa II
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Subset of samples collected from JAXA asteroid mission to (162173) 1999

Our Near Future . . .

OSIRIS-REx
(2023)
Asteroid sample return from 101955 Bennu

OSIRIS-REx
ASTEROID SAMPLE RETURN MISSION

Artemis
(~2026)
Lunar polar region; Lunar rocks, soils, and volatiles

ARTEMIS

Authority from NPD 7100.10F + derivative NPR

Our More Distant Future . . .

Moon
(2020s)
Non-volatile-rich farside/polar sample return

Next New Frontiers Call

Comet
(2020s)
Cold curated (?) surface sample return from a comet

Next New Frontiers Call

Phobos
(late 2020s)
10% of a JAXA mission to bring back Phobos material

JAXA sample return mission
MMX

Mars
(~2030+)

Various Mars Sample Return

Over 50 years in the planning (est. 1964)

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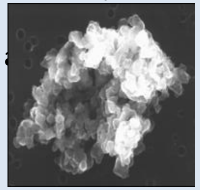

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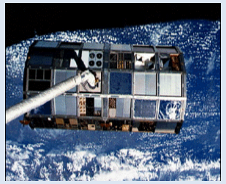

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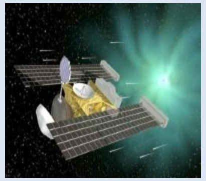

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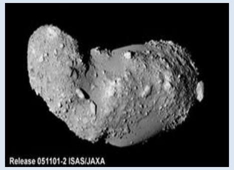

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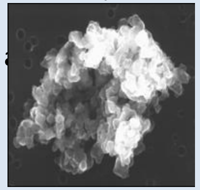

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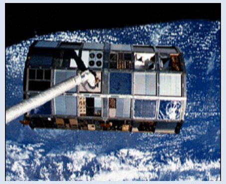

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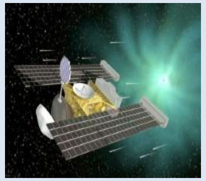

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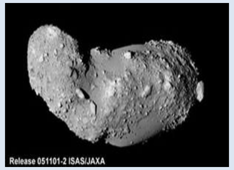

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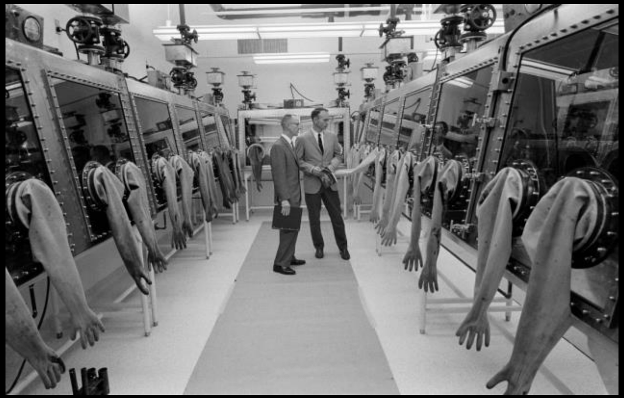
Lunar Receiving Lab for Apollo Restricted Missions

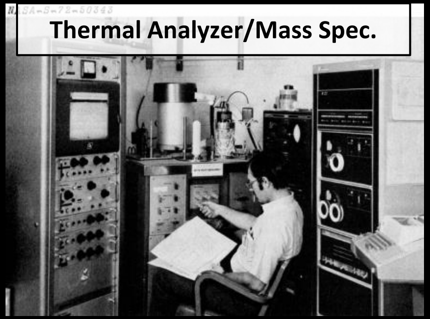
The 84,326 ft^2 (7,834 m^2) LRL facility was designed to the following functional requirements:

- Biological quarantine of astronauts, spacecraft, equipment, and samples
- Biohazard clearance testing
- Preparation of sample return containers and astronaut geologic hand tools before flight
- Receiving sample return containers and conducting preliminary sample characterization
- Time-sensitive primary scientific analyses
- Sample curation: cataloging, sample storage, re-packaging and distribution of lunar samples to the scientific community for analysis

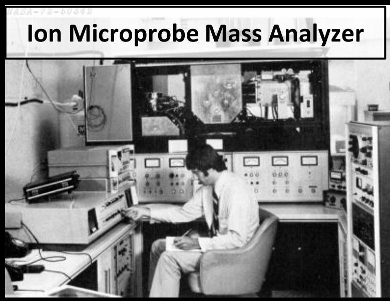
Lunar Receiving Lab for Apollo Restricted Missions

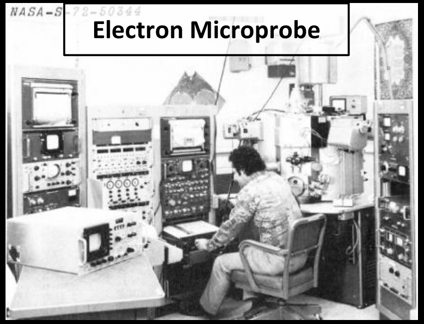
1967 Site Aerial Photo

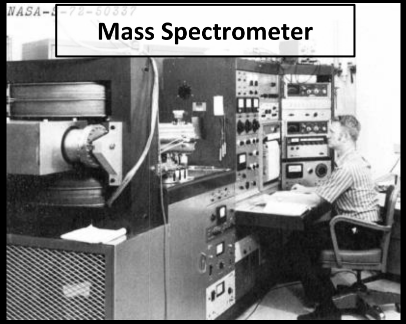


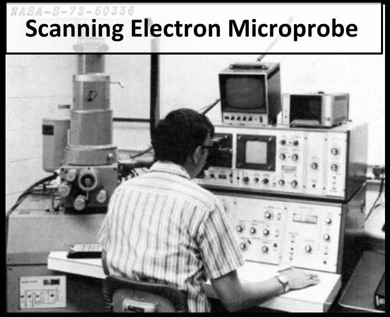

Thermal Analyzer/Mass Spec.


Single-Crystal X-Ray Diffractometer


Ion Microprobe Mass Analyzer


Electron Microprobe


Mass Spectrometer


Scanning Electron Microprobe

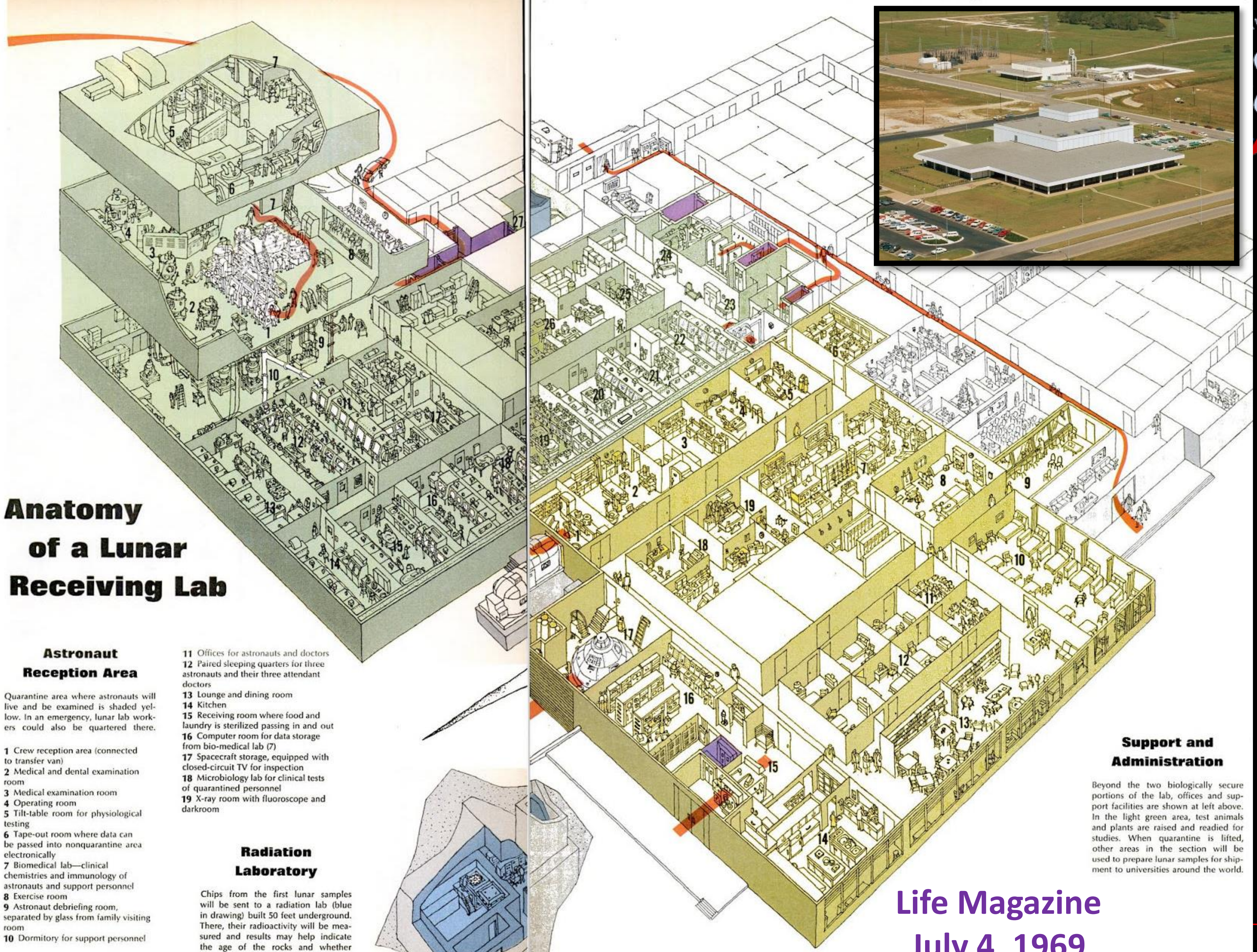
Anatomy of a Lunar Receiving Lab

Routes into biologically isolated sectors of the Lunar Receiving Lab are shown here by red lines. At upper left, lunar samples arrive and are taken to vacuum system and radiation lab by elevator. Other entrances indicated are for astronauts, for the command module, for food and laundry. Lines at far right show where lab personnel come and go through ultraviolet airlocks (purple).

Lunar Sample Laboratory

More than 100 scientists and technicians will perform tests with lunar materials in the lab area, shaded green.

1 Vacuum system where lunar material is received and processed
2 Carousels for storage and transfer of lunar material
3 Controls for vacuum system
4 Equipment for preflight tool sterilization
5 Gas analysis laboratory
6 Special air conditioning system to sterilize air entering and leaving building
7 Elevator
8 Viewing room for participating scientists
9 Pump room and electrical support equipment for vacuum system
10 Transfer tubes for moving samples directly from vacuum system to labs
11 Physical-chemical test lab—mineralogy, petrology, geochemistry
12 Bio-preparation lab where lunar material is prepared, weighed and packaged for distribution
13 Bio-analysis lab for blood tests and other tests on mice
14 Holding lab for germ-free mice
15 Holding lab for conventional mice
16 Lunar microbiology lab to isolate, identify and possibly grow lunar micro-organisms
17 Spectrographic lab and darkroom (connects to 11)
18 Bird, fish and invertebrate lab where shrimp, quail, cockroaches, oysters and other creatures are exposed to lunar material
19 Microbiology lab for test cultures of lunar and astronaut material
20 Egg and tissue culture lab (support and additional facilities for 21)
21 Crew virology lab for postflight virological analysis of astronauts
22 Plant lab where germ-free algae, spores, seeds and seedlings will be exposed to lunar material
23 Entrance to lunar sample operations area. Showers and facilities for all personnel passing in and out to change clothing
24 Autoclave for sterilizing all material entering or leaving area
25 Bio-safety lab to monitor all systems
26 Support offices
27 Entrance to radiation counting lab



Astronaut Reception Area

Quarantine area where astronauts will live and be examined is shaded yellow. In an emergency, lunar lab workers could also be quartered there.

1 Crew reception area (connected to transfer van)
2 Medical and dental examination room
3 Medical examination room
4 Operating room
5 Tilt-table room for physiological testing
6 Tape-out room where data can be passed into nonquarantine area electronically
7 Biomedical lab—clinical chemistries and immunology of astronauts and support personnel
8 Exercise room
9 Astronaut debriefing room, separated by glass from family visiting room
10 Dormitory for support personnel
11 Offices for astronauts and doctors
12 Paired sleeping quarters for three astronauts and their three attendant doctors
13 Lounge and dining room
14 Kitchen
15 Receiving room where food and laundry is sterilized passing in and out
16 Computer room for data storage from bio-medical lab (7)
17 Spacecraft storage, equipped with closed-circuit TV for inspection
18 Microbiology lab for clinical tests of quarantined personnel
19 X-ray room with fluoroscope and darkroom

Radiation Laboratory

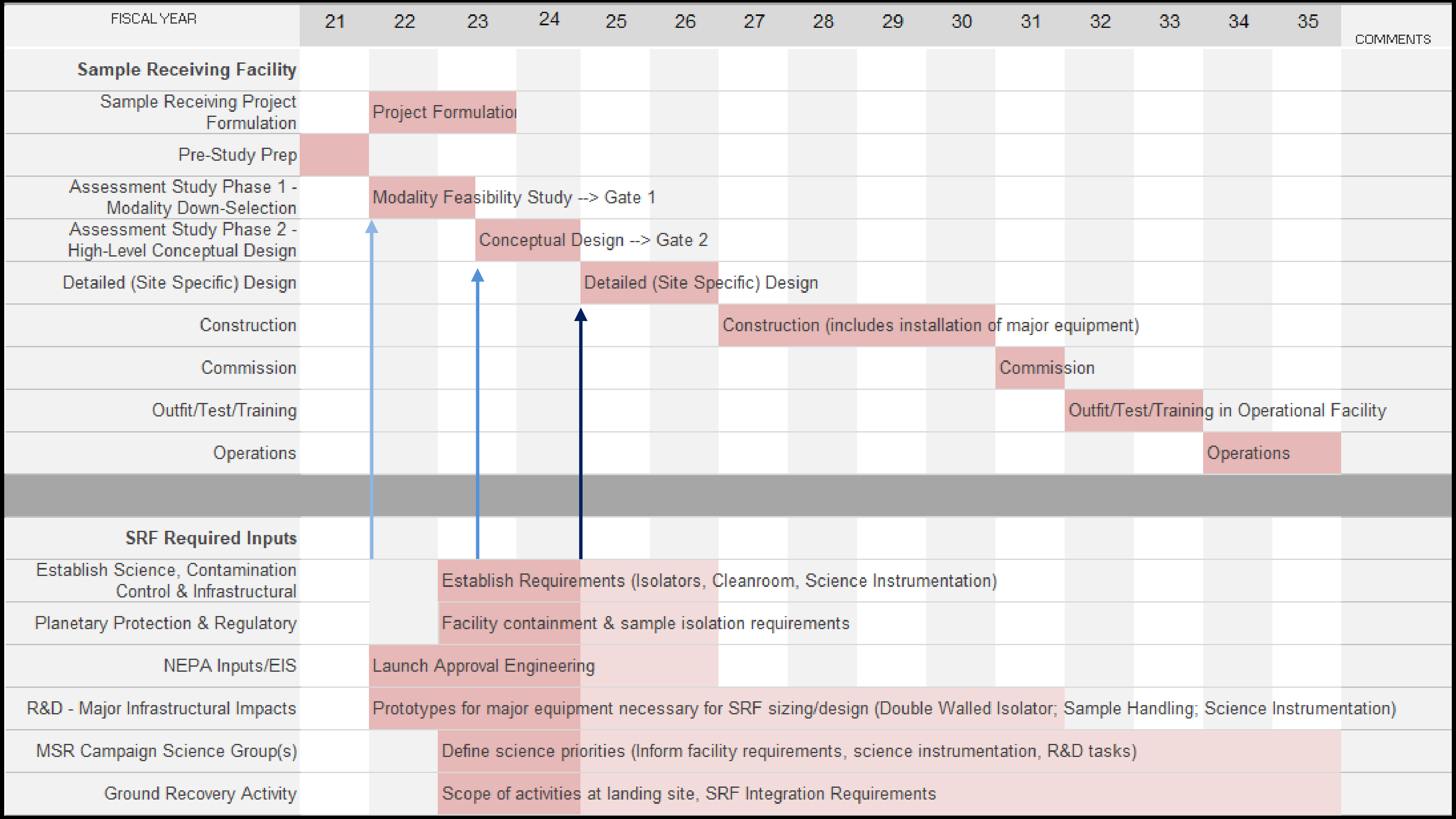
Chips from the first lunar samples will be sent to a radiation lab (blue in drawing) built 50 feet underground. There, their radioactivity will be measured and results may help indicate the age of the rocks and whether they ever existed in molten form.

Support and Administration

Beyond the two biologically secure portions of the lab, offices and support facilities are shown at left above. In the light green area, test animals and plants are raised and readied for studies. When quarantine is lifted, other areas in the section will be used to prepare lunar samples for shipment to universities around the world.

Life Magazine
July 4, 1969

MSR SRP High-Level Notional Schedule



Inform Site-Specific Design
Major infrastructural impacts

Refine Workflows
Minor infrastructural impacts

Finalize Instrumentation
No infrastructural changes possible without schedule slip (programmatic risk)

- Sample Receiving Facility (SRF) readiness is driving schedule
- Outputs from International MSR Working Groups (e.g., MSPG2, SSAF) are foundational for planning
- Refinement of guidelines into requirements is a priority to inform site-specific design
- PP considerations are a priority and span from major infrastructure to instruments and workflows

Activities Implementing Planetary Protection Requirements

- Ground Recovery Activities
  - Safe capture and containment and sample transportation from UTTR to SRF
  - NEPA MSR PEIS Tier I: Site-Specific Analysis of Flight Elements (includes the site-specific proposal to land the vehicle containing the samples at UTTR); (Draft PEIS released 11/4)
- Sample Receiving Facility (SRF)
  - Investigate infrastructural options and requirements to accommodate the curation and science instruments needed to generate a sample catalogue, perform the biohazard assessment, and select early science.
  - NEPA MSR PEIS Tier II: Site-Specific Analysis of Ground Elements (sample transportation from UTTR and SRF)
- Research and Development
  - Support SRF studies, enable pristine and contained sample processing/storage, and sterilization verification for samples and equipment
- Contamination Knowledge Samples
  - Witness and reference items collected during ATLO to be utilized as scientific baselines
- Biohazard Testing Protocol
  - COSPAR Sample Safety Assessment Framework - Evaluates whether there is Martian life present in the samples that could be released into Earth's systems (e.g., environment, biosphere, geochemical cycles).
  - Sample Safety Assessment Protocol is not yet defined
- MSR Safety Assurance Case Approach for Backwards Planetary Protection (BPP)
  - A campaign level safety assurance case is being led by the MSR Program

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Curation Supporting and Implementing

Activities Implementing Planetary Protection Requirements

Today's Focus

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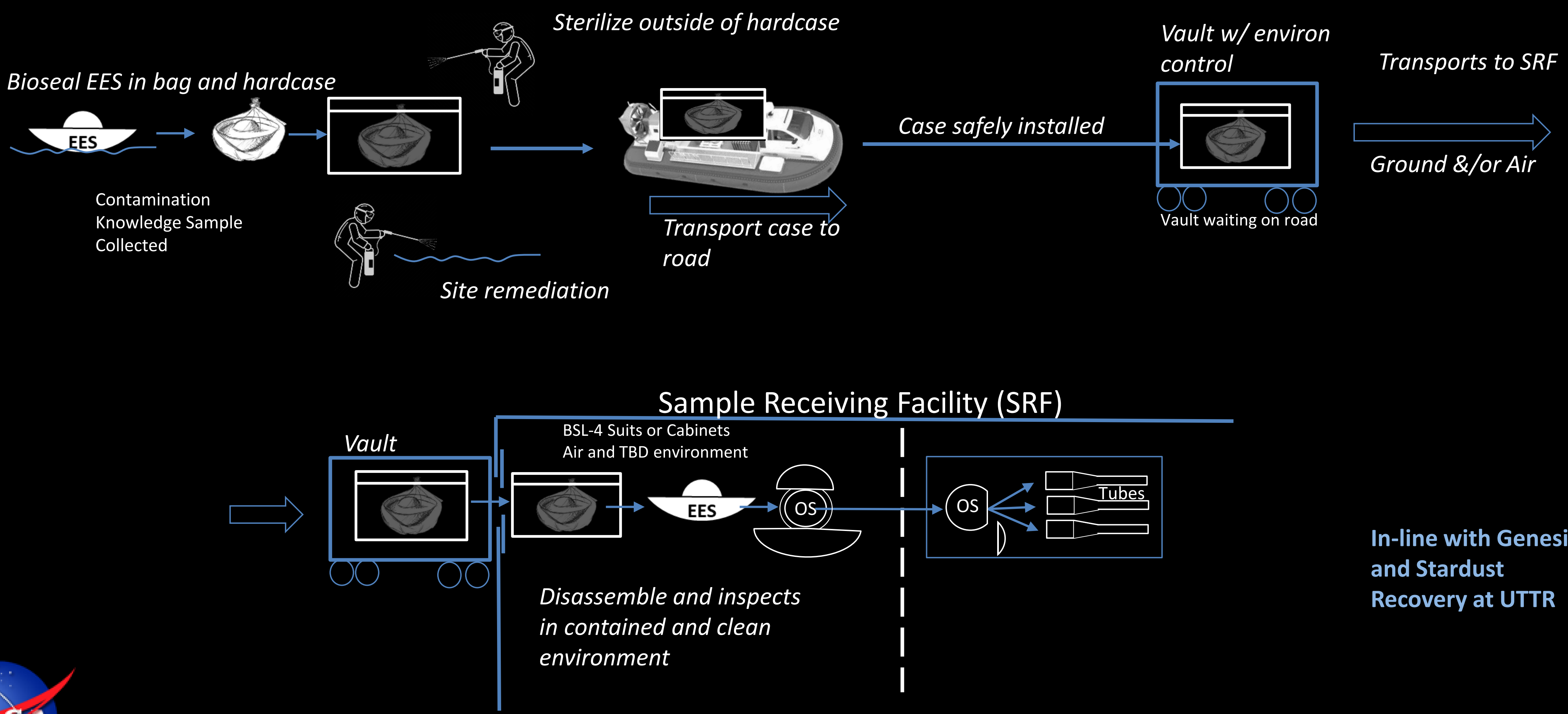
Notional Ground Recovery Activity



In-line with Genesis and Stardust Recovery at UTTR

MSR SRF Capabilities and Priorities

Receive Spacecraft

Hardware Disassembly

Sample Tube Pre-Basic Characterization

Samples Opened and Basic Characterization

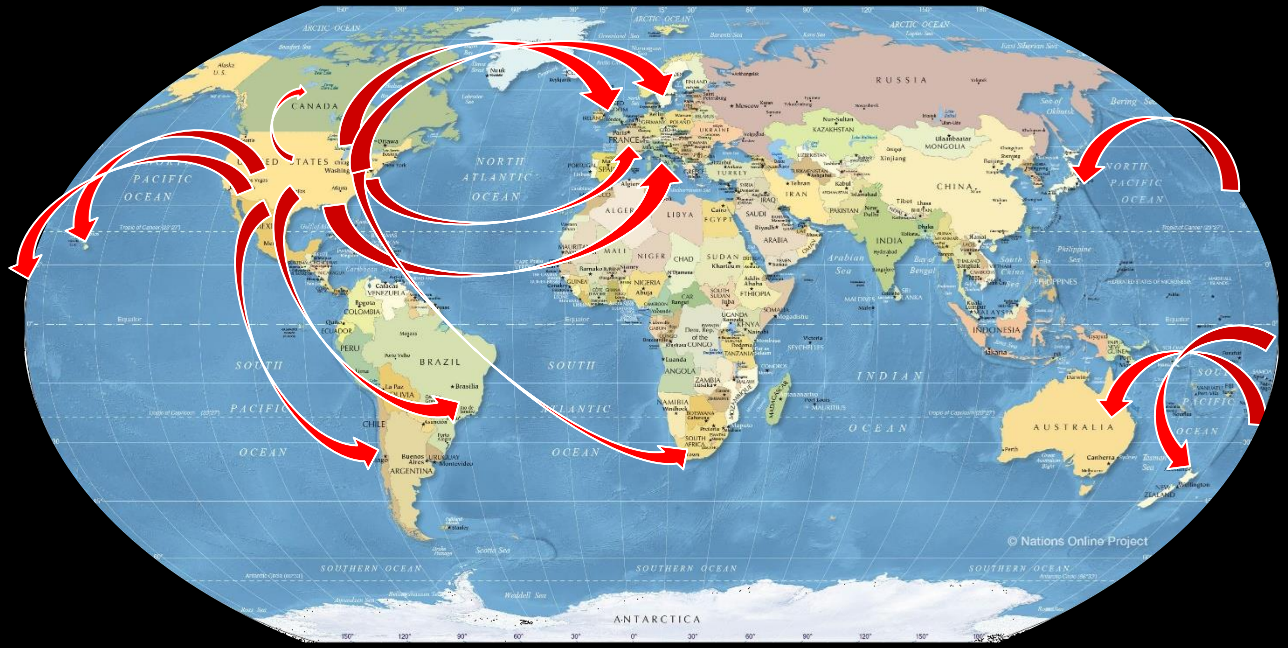
Samples Picked and/or subdivided

Biohazard Assessment, Preliminary Examination, and/or Select Early Science

Allocated Sample Sterilization Process (Irradiation or Heat)

~72% of science investigations concerning geological phenomena that include past interactions with the hydrosphere and atmosphere can be performed on sterilized samples. (see MSPG-2)

~14% of science investigations concerning the presence of (mostly molecular) biosignatures can be performed on sterilized samples. (see MSPG-2)



Global Safe Sample Distribution for Earth-based Science Investigations

Mars Sample Receiving Facility (SRF) Initial Assumptions

- The SRF is a short-term facility or facilities (2-5 year nominally) that should be fully operational by sample arrival and able to accommodate the highest priority instrumentation for curation, biohazard assessment, and select early/competed science.

- The SRF should also provide **high-containment** for all Martian material and keep the samples **pristine.**
  - **Containment** is assumed to be at Biological Safety Level **(BSL)-4**, the highest level available.
    - Appropriate for the most infectious terrestrial pathogens
  - **Pristine** assumes, at minimum, contamination control (CC) levels met by M2020 for sample-intimate hardware.
    - This is **subject to future trades analysis**.

BSL-4 Containment Facility Options

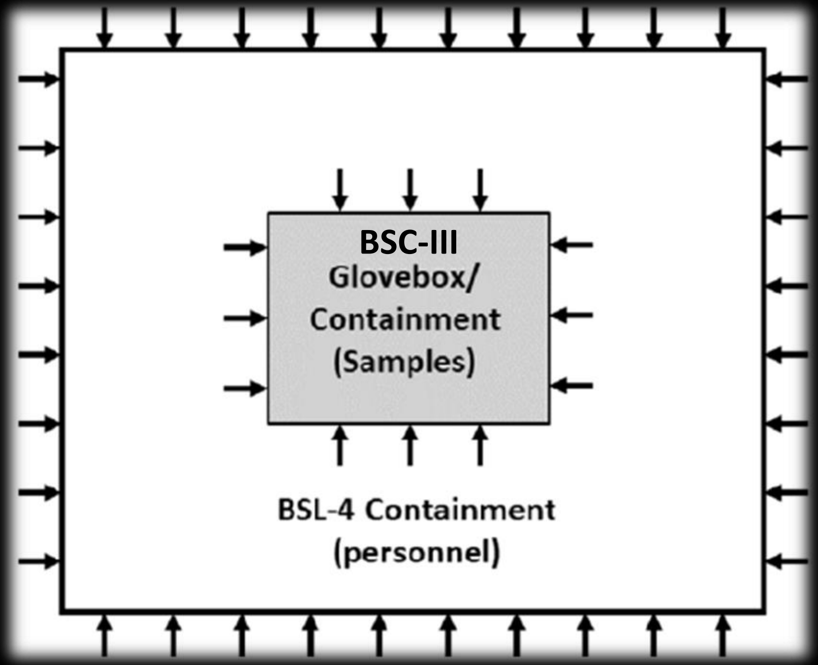
Personnel in Pressure Suits

Shope (USA)

Biosafety Cabinet (BSC)-III Cabinet Line

Porton Down (UK)

Traditional high-containment facilities are designed to protect scientists and the community from exposure to known hazard(s).



Negative Pressure Environment(s)

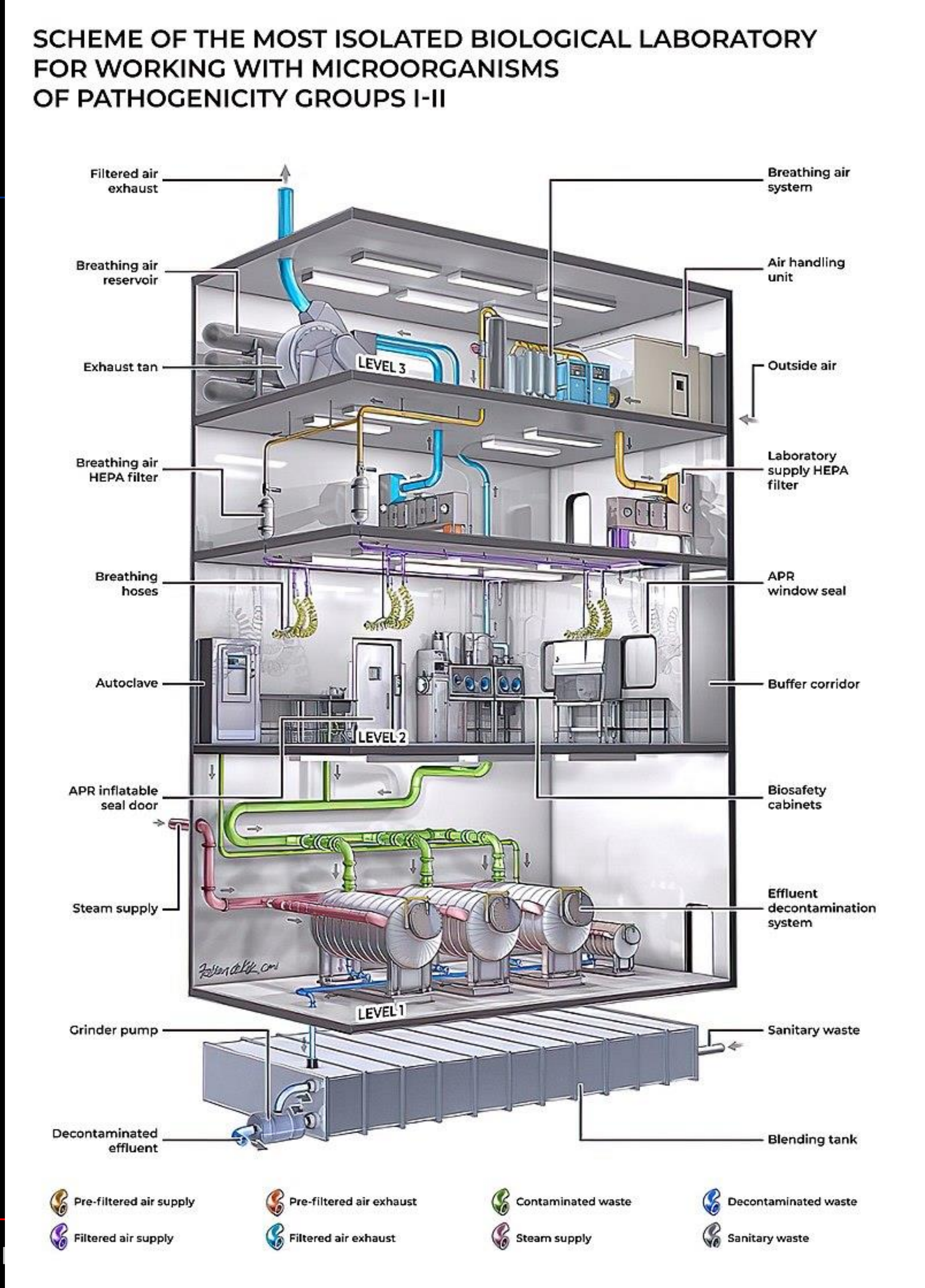
BSL-4 Containment Facility

Personnel in Pressure Suits

Shope (USA)

Biosafety Cabinet (BSC)-III Cabinet Line

Porton Down (UK)



Pristine Facility Options

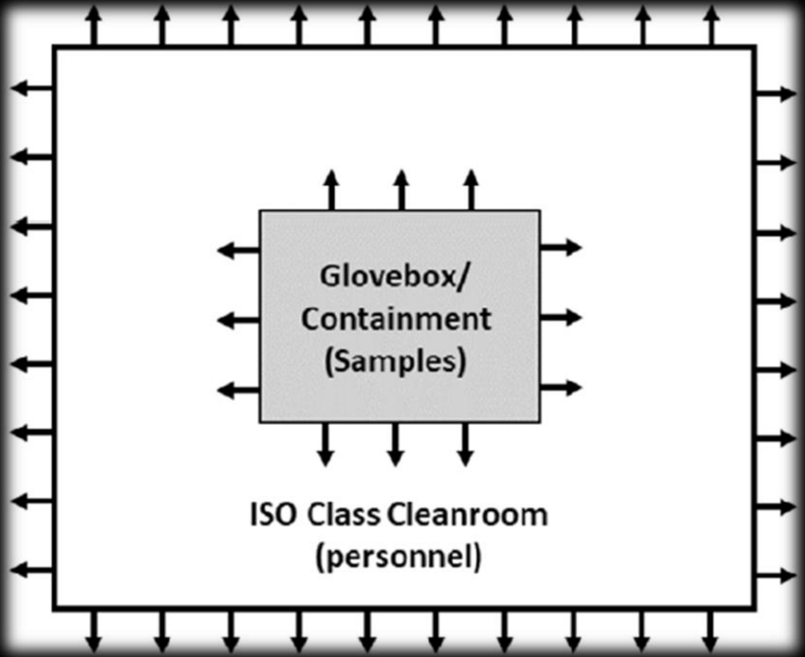
Cleanroom in Full Bunny Suits

Cosmic Dust Laboratory JSC

Gloveboxes

Apollo Laboratory JSC

Properly handling, examining, and curating Martian samples also requires that the samples be protected from terrestrial contamination so Planetary Protection (PP) and Science investigations are not impeded.



Positive Pressure Environment(s)

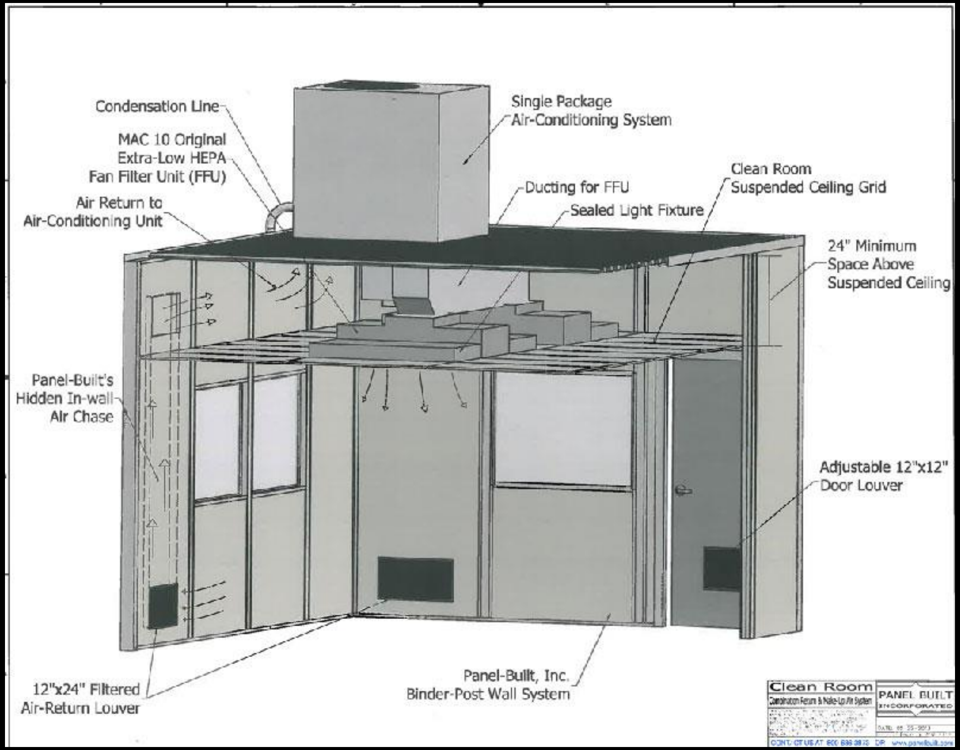
Pristine Facility Options

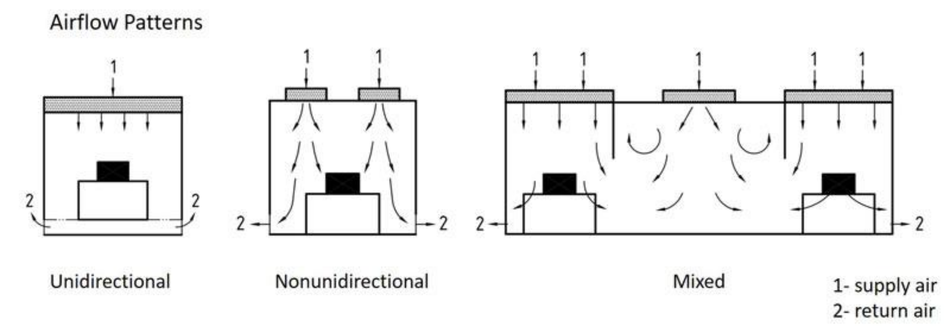
Cleanroom in Full Bunny Suits

Cosmic Dust Laboratory JSC

Gloveboxes

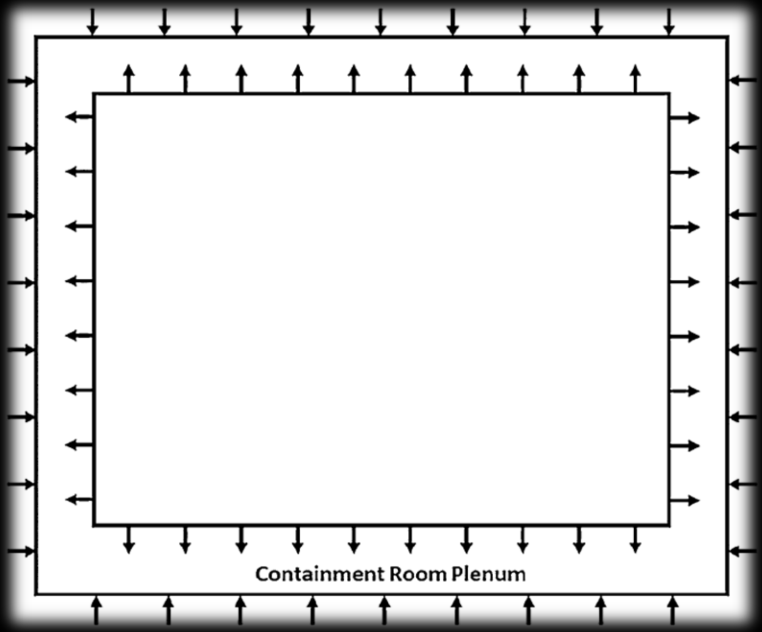
Apollo Laboratory JSC





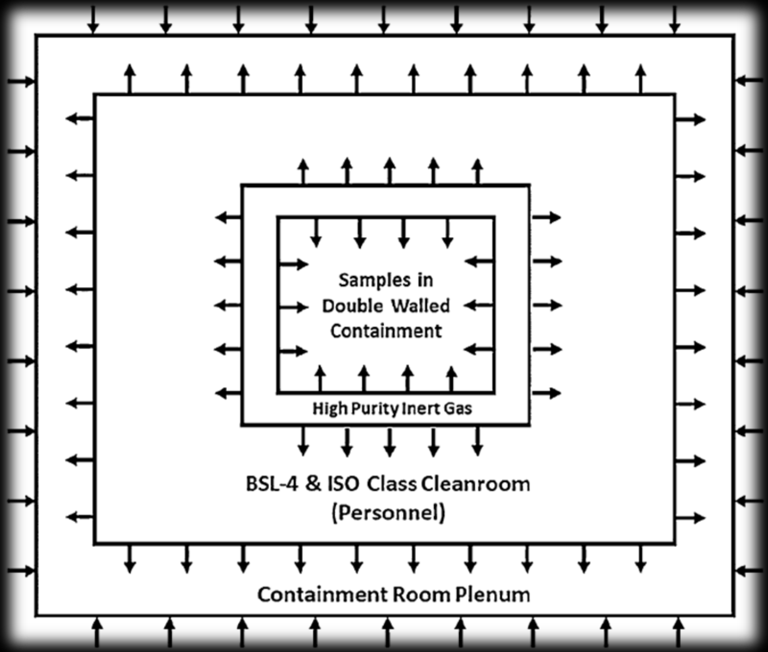
This combined effort requires the integration of both negative and positive pressure environments to meet the needs of PP and contamination control (CC).

Pristine Cleanroom Facilities within High Biological BSL-4 Containment



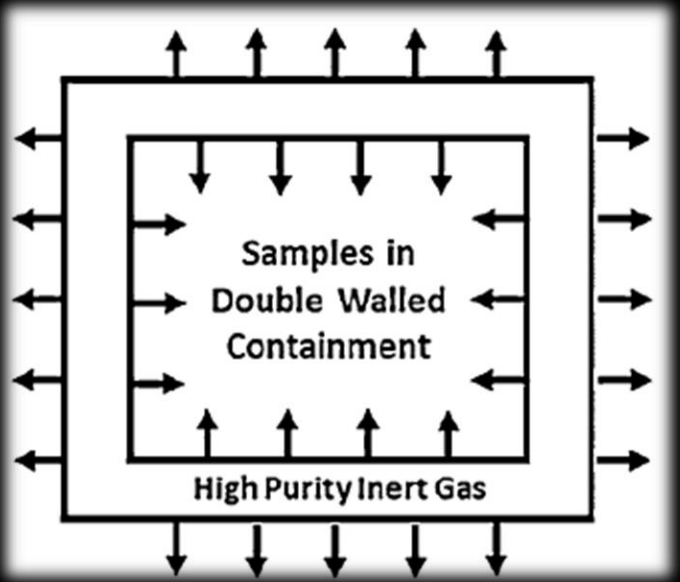
Outermost layer is negative pressure/containment to offer the greatest protection.

Combined facility and specialized isolator approach



This measure may be necessary to ensure sample pristinity is not lost to sterilization in an off-nominal event.

BSC-III Cabinet within a Pristine Glovebox



Innermost layer is negative pressure/containment to offer the greatest protection.

Highlight of Overarching Considerations

Mars Sample Receiving Facility (SRF) Assessment Study (MSAS) –
Assess the utilization of 4 modality options and accommodation potentialities

Structural Constraints
Personnel Safety
PP Requirements
CC Requirements
Preliminary Examination Requirements
Science Requirements
Construction Timeline
Operational Timeline
Adaptability to Changing Needs
Facility Fair Use/Access to Samples
Partnership/Reutilization Opportunities
Cost Effectiveness (short and long-term)

European Extraterrestrial Sample Infrastructure (EETSI) System Study –
Delivers preliminary designs, costs, and schedules for a new traditional fixed SRF and SCF

Upon completion of the assessment studies, the preferred modality and refined requirements would be utilized for site-specific design but will not be finalized until NASA's completion of the National Environmental Policy Act (NEPA) process.

MSAS SRF Modality Options

Traditional Fixed – Brick and Mortar

Dept. of Homeland Security
New USDA NBAF BSL-4 Facility

Utilize Existing BSL-4 Facility or Facilities

USAMRIID at Fort Detrick, MD

Modular Construction

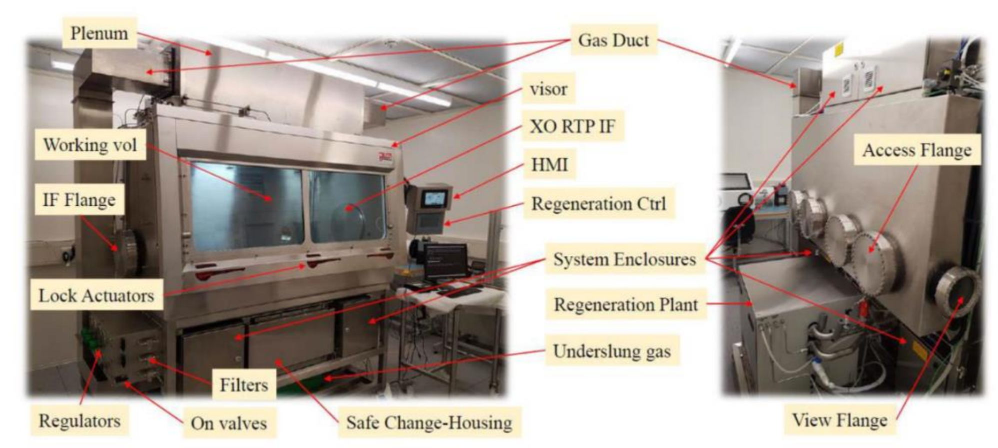
Germfree BSL-3+ Modular Facilities

Hybrid of Multiple Facility Modalities

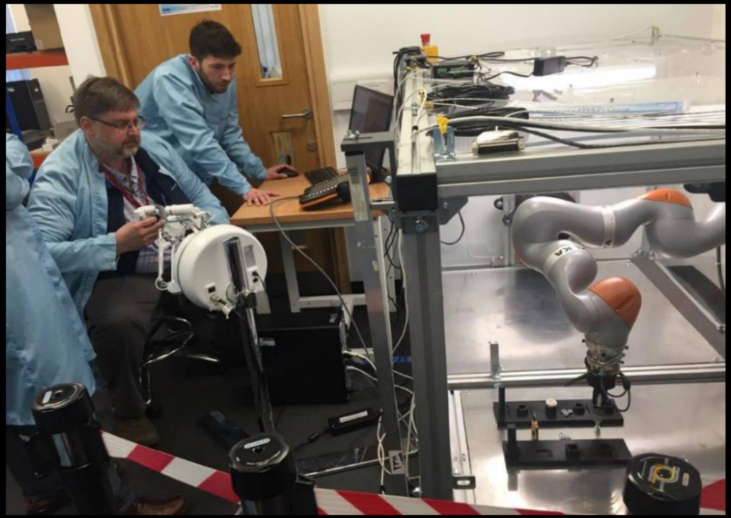
modular **+** *constructed annex (shell)* **@** *existing BSL-4*

Research & Development in Support of SRF Design & Ops

- Double Walled Isolator (DWI) Design
- Sample handling - Robotic and/or Remote Manipulation
- Sample Tube and Subsample Isolation Containers for Analyses Outside SRF
- High-Containment suit and infrastructural material contamination control testing
- Quantify contamination loads of existing BSL-4 facilities
- Instrument accommodations
- Sample sterilization
- Infrastructural cleaning and sterilization procedures



DWI Breadboard at U. Leicester



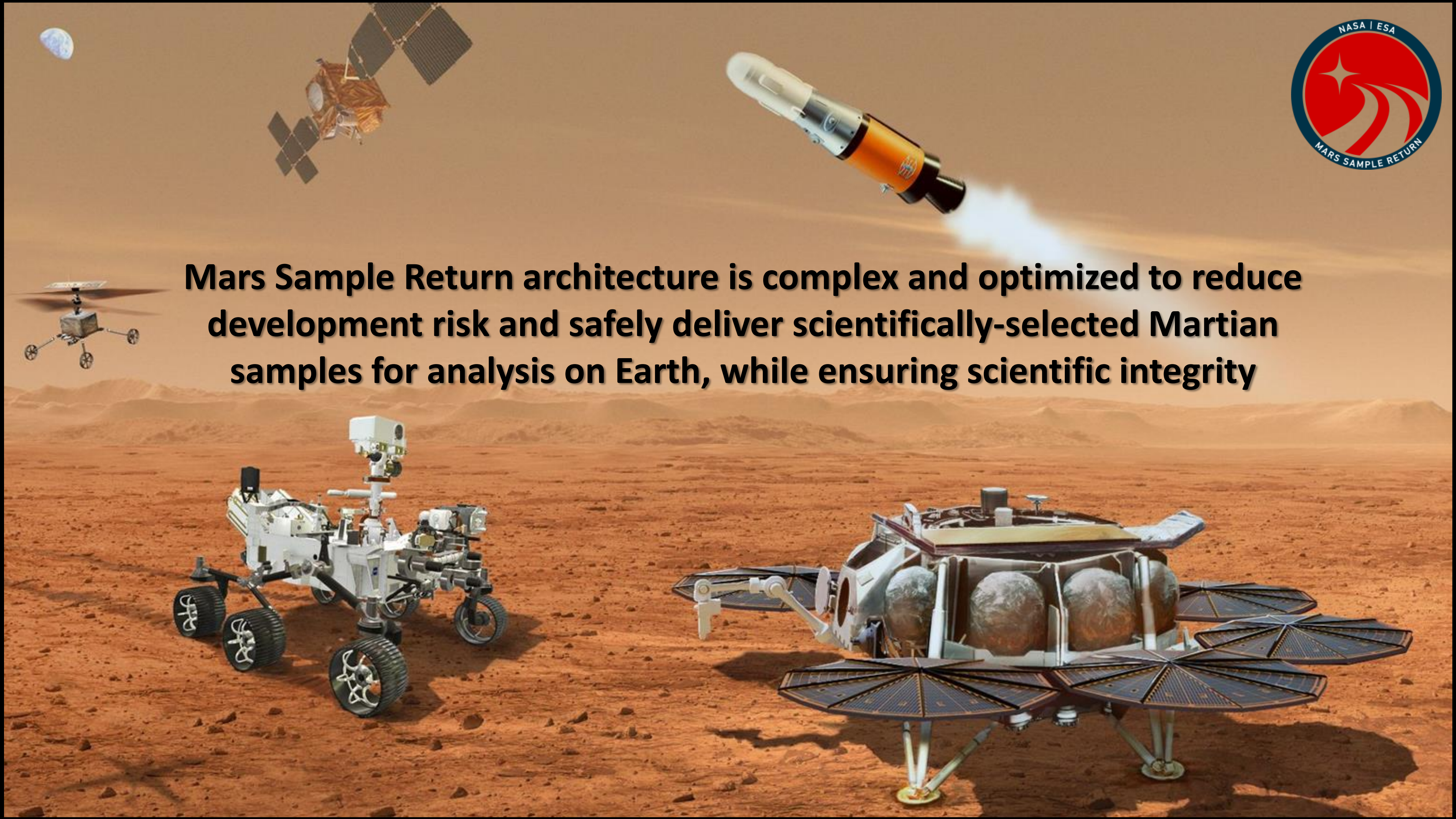
Robotic Manipulation Breadboard at Thales Alenia UK

Close collaboration between NASA/ESA's Curation, Science, and PP Teams

Closing Highlights

- The Curation Office integrates requirements and develops implementation strategies for meeting the array of requirements levied on the collection and associated facilities.
- NASA and ESA are taking a “safety first” approach to designing and engineering every step of MSR.
  - Complementary NASA/ESA SRF studies will inform site-specific design.
  - The array of R&D activities with Planetary Protection implications prioritized.
- The nature of MSR ground operations planning requires effective communication across Agencies (national and international), Centers, the scientific community, and the general public.

QUESTIONS & DISCUSSION



Samples Collected During ATLO

Witness Items →

Contamination Control

Spacecraft & Sample Integrity

Contamination Control manages molecular, particulate, and biological contamination that can degrade or compromise: 1) the performance of the spacecraft and 2) the scientific investigations on returned samples.

Governed by the Mission

Planetary Protection

Forward & Backward Contamination

Planetary Protection involves protecting the planet we are visiting and protecting the Earth from harmful organic or biological elements when we return samples, contaminated spacecraft, or astronauts.

Governed by the Planetary Protection Office

Witness Items →

Reference Materials

Contamination Knowledge

Scientific Baselines

Contamination Knowledge is the information gained from studying the collected/curated reference materials and witness plates in conjunction with returned sample analysis.

Governed by the Astromaterials Acquisition and Curation Office

Reference Materials →

Engineering Knowledge

Troubleshooting

Information gained from engineering models after launch.

Governed by the Mission

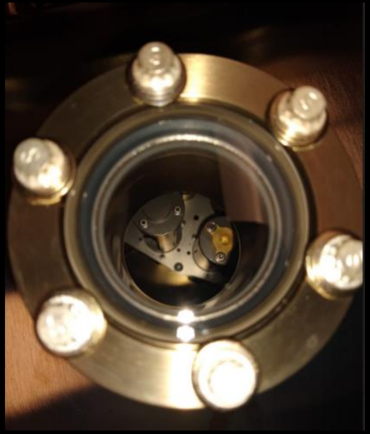
Each sample type of sample is for distinct objectives

CC and PP data can be complementary to CK

MARS SAMPLE RETURN CK COLLECTION (GENETIC & CC DATA)

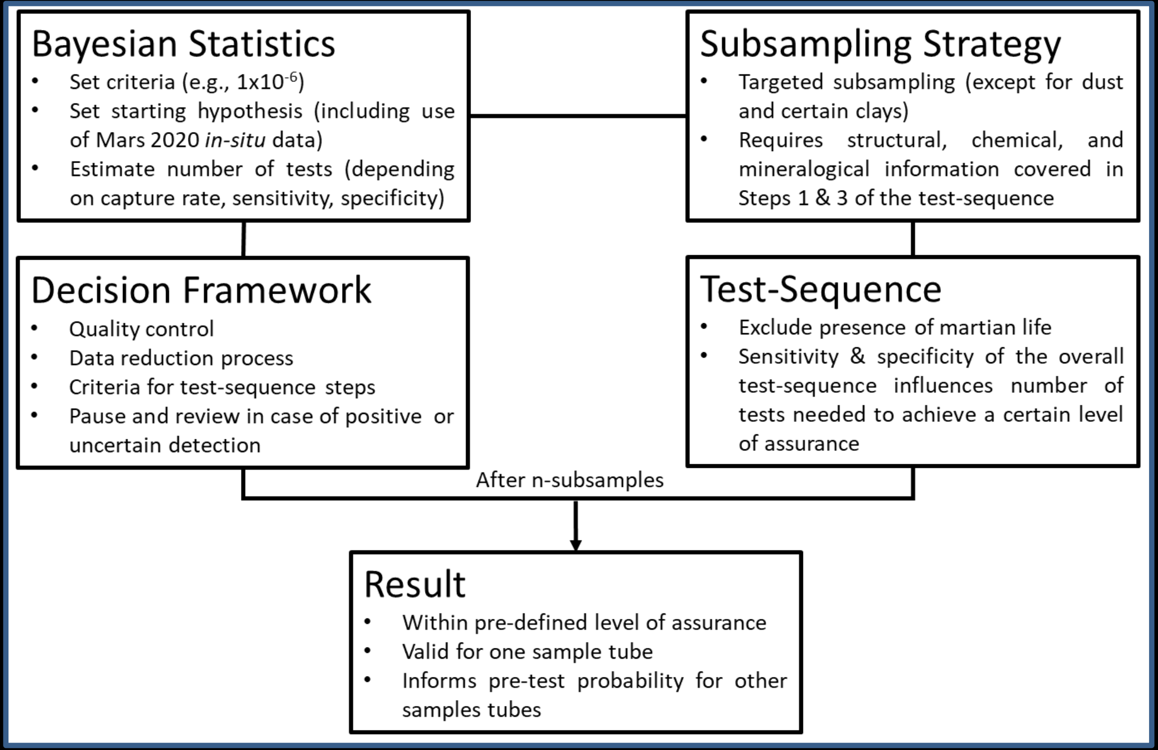
- Biological CK
  - Swabs
  - Wipes
- Flight Vacuum Bake-Out Witness Plates
- Flight Replicates
  - Sample Tubes
  - Drill Bit
  - Coring Bit
  - Abrading Bit
  - Drillable Blank
- Environmental Witness Plates & Foils
  - SIH Flow Benches
  - Assembly Rooms
  - Organic
  - Inorganic
- SIH Witness Items
  - Gloves
  - Wipes

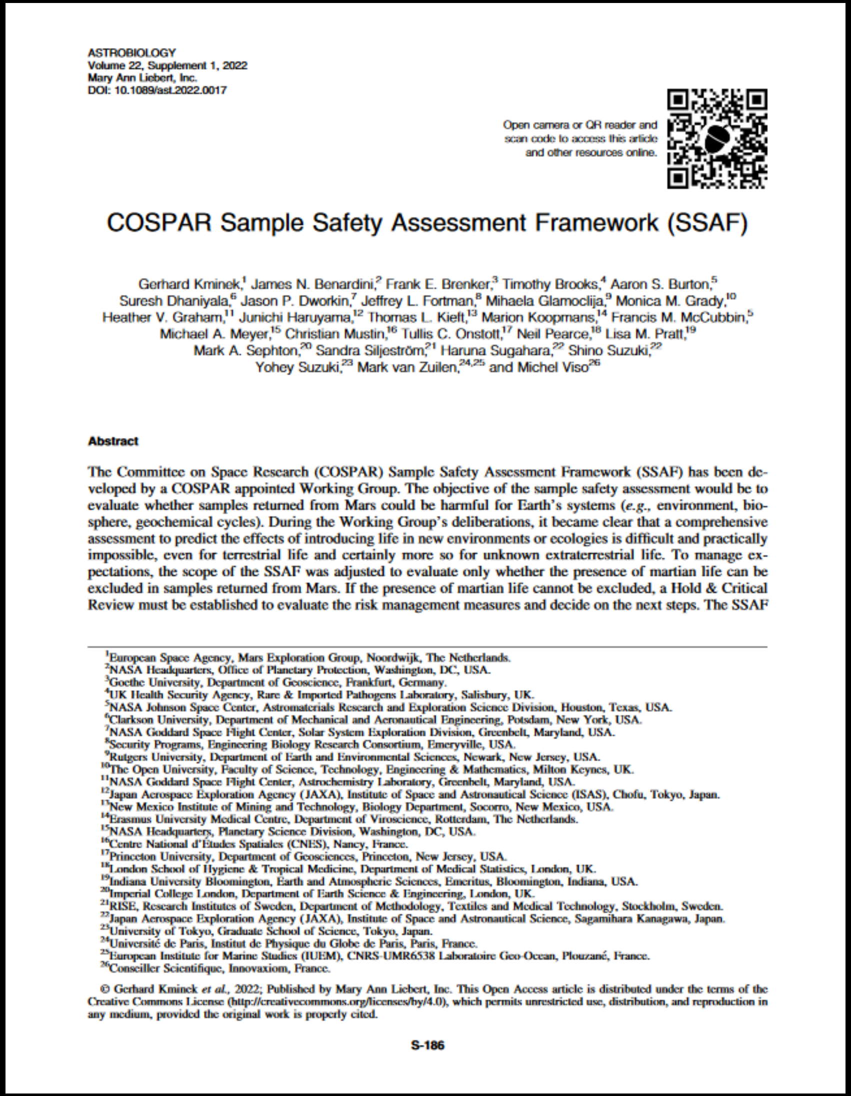
- Flight Replicates
  - SHERLOC Cal Target
  - 7 Sample Tube Assemblies
  - 7 Glove Assemblies
  - 7 Sample Tube Storage
  - Volume Station Assembly
  - Seal Dispenser Assembly
  - 7 Hermetic Seal Assemblies
  - 2 Cover Assemblies
  - 2 Witness Tube Assemblies
- Material Samples
- Final Solvent Rinses
  - Hexane
  - Isopropanol
  - Acetone
  - Ethanol
  - DI Water



The Sample Safety Assessment Framework

- Framework to “evaluate only whether the presence of martian life can be excluded in samples returned from Mars.”
- Considers only carbon-based life
- It is a Framework – detailed Protocol still tbd





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COSPAR Sample Safety Assessment Framework (SSAF)

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Abstract

The Committee on Space Research (COSPAR) Sample Safety Assessment Framework (SSAF) has been developed by a COSPAR appointed Working Group. The objective of the sample safety assessment would be to evaluate whether samples returned from Mars could be harmful for Earth’s systems (*e.g.*, environment, biosphere, geochemical cycles). During the Working Group’s deliberations, it became clear that a comprehensive assessment to predict the effects of introducing life in new environments or ecologies is difficult and practically impossible, even for terrestrial life and certainly more so for unknown extraterrestrial life. To manage expectations, the scope of the SSAF was adjusted to evaluate only whether the presence of martian life can be excluded in samples returned from Mars. If the presence of martian life cannot be excluded, a Hold & Critical Review must be established to evaluate the risk management measures and decide on the next steps. The SSAF

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