Planetary Protection Technologies: Technical Challenges for Mars Exploration

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Search for Life Drives PP Technology

Current Technology

- Standard Cleaning Processes
- NASA Standard Spore Assay
- Dry Heat Microbial Reduction

Current Missions

Search for Life → Biologically interesting targets → Increased PP Requirements

- Hydrogen peroxide and other approaches for h/w sterilization
- Alternate assay procedures
- Improved cleaning
- Research on microbe survivability
- Architectures that facilitate sterilization
- Sample containment and Earth return

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PP Categories for Mars Landed Missions
w/Current Representative Requirements

Cat IV applies to any lander or probe to Mars

Cat V: Earth return

IVa

- No extant life detection experiments
- Bioburden reduction required
- Clean to average of <300 cultivable aerobic spores/sq meter*
- Verify by bioassay

IVb

- Extant life detection experiments
- Bioburden reduction required
- Verify pre-sterilization cleanliness by bioassay
- Surface sterilization required
- Bioshield to prevent recontamination

IVc

- Investigate martian special regions
- Not driven by life detection experiments
- Bioburden reduction required
- Range of implementation options (system vs subsystem; surface vs bulk)
- Bioshield to prevent recontamination

V

- Strict prelaunch microbial controls
- Microbial/organic materials archive
- Stringent measures to avoid unplanned Earth impact
- Containment of any sample
- Sample quarantine and assessment (sample receiving facility)

***<300 cultivable aerobic spores/m^2 ≈ <300,000 viable organisms/m^2 of all types**

PP Technologies for Mars Missions

Prelaunch/Operations Technologies

- Cleaning to sterility (JPL)
- Assays for rapid assessment of cleanliness—cultivable, non-cultivable, molecular
- Particle transport models
- Development of Mars orbital debris analysis code
- Aseptic assembly systems
- Vapor hydrogen peroxide and/or radiation sterilization of assembled subsystem

Launched Hardware

- Lightweight biobarriers for forward-contamination prevention
- *In situ* sterilization systems
- Container sealing systems
- Mechanism or series of mechanisms for "break-the-chain" of contact
- Earth targeting improvements
- Earth entry vehicle for assured containment
- Meteoroid protection on spacecraft

Sample Handling Systems

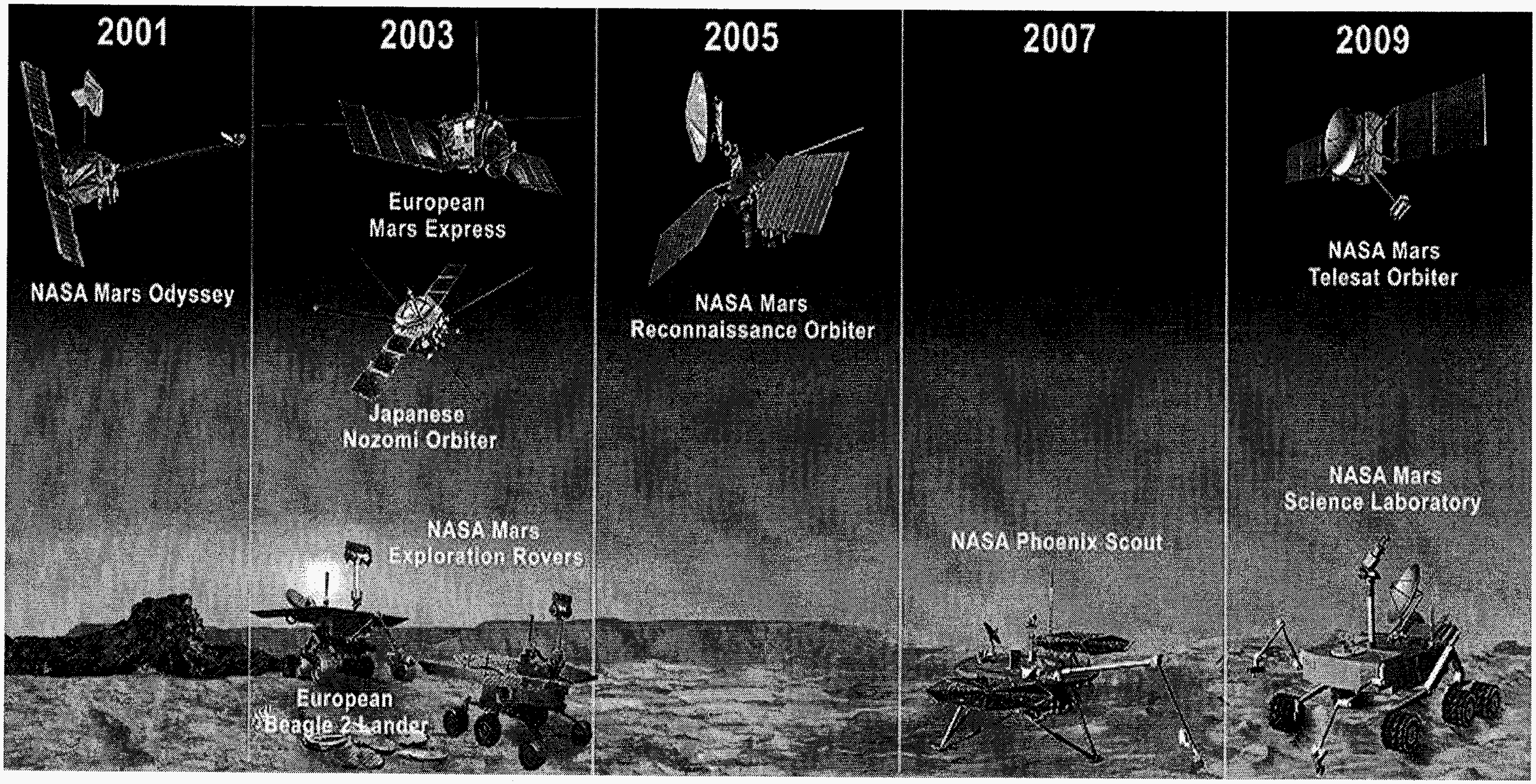
- Multi-directional containment systems for sample handling
- Systems for analysis of contained samples (Sample Receiving Facility)

Research Required to Inform the Development of Technologies

- Fundamental biology of survivability (microbial characterization in flight hardware manufacturing environments)
- Advanced spacecraft designs to provide for sterilization and aseptic assembly
- Materials screening to enable system/subsystem sterilization

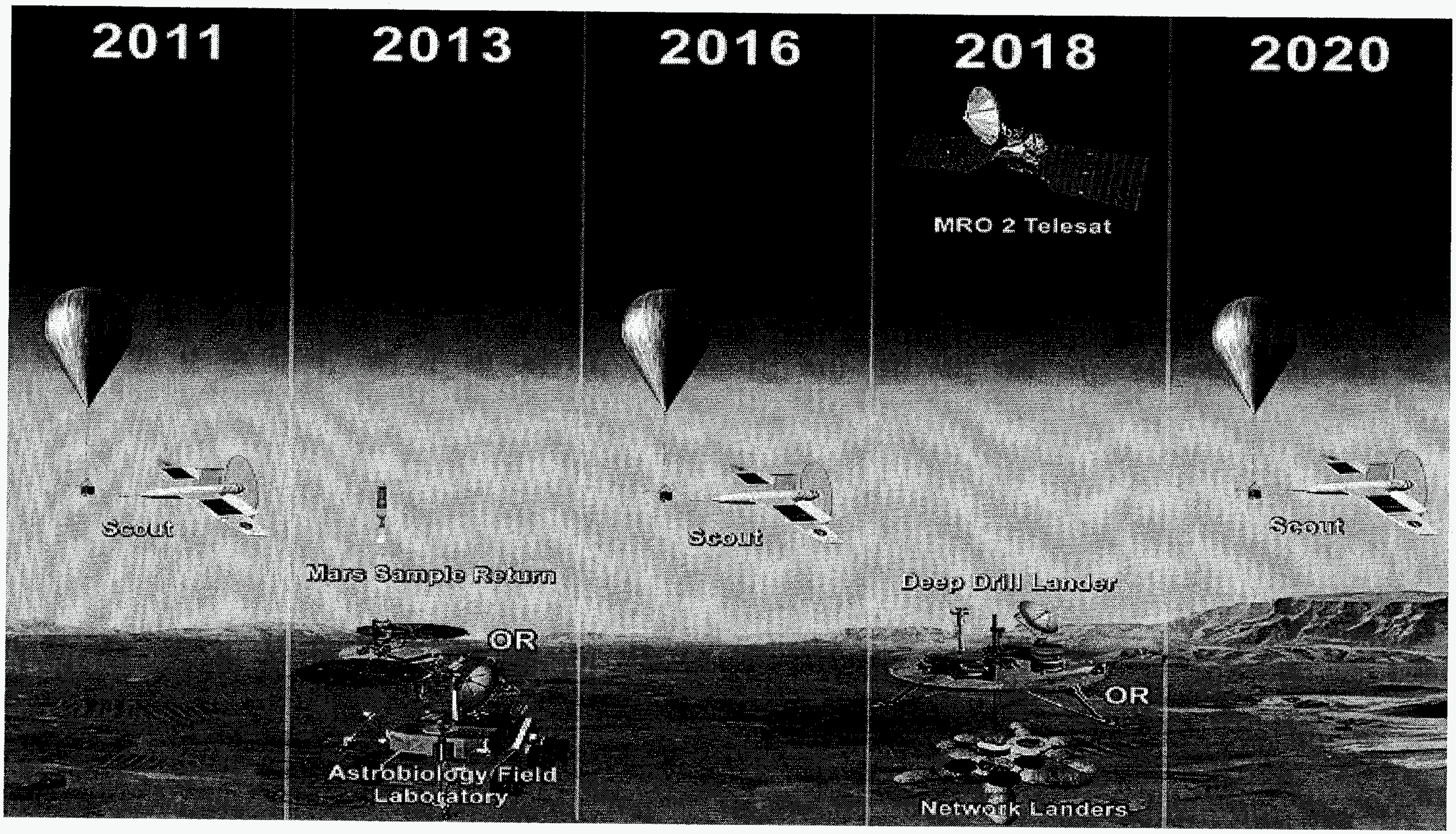
Mars Exploration Pathway

This Decade (planned)

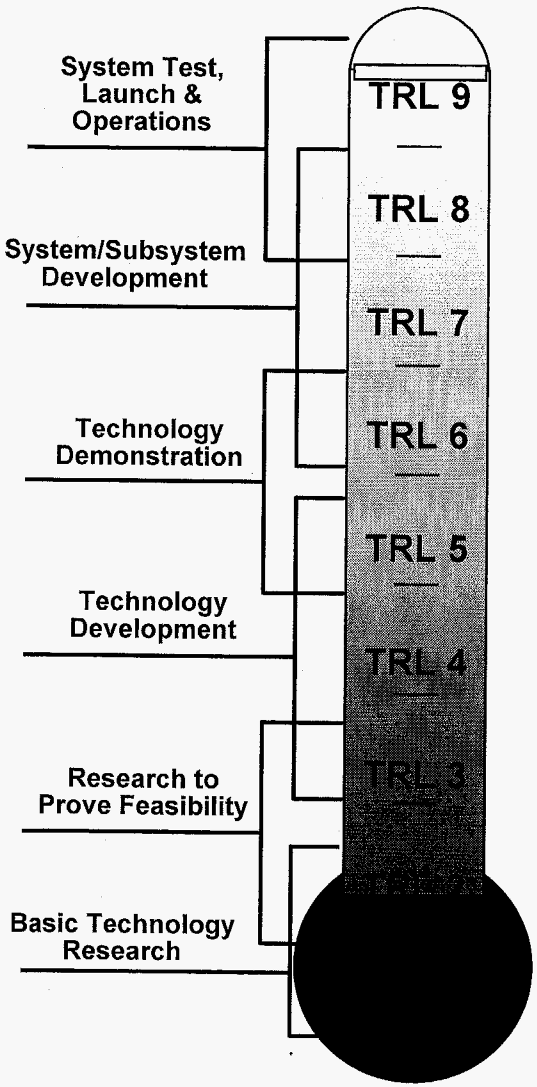


Mars Exploration Pathway

Next Decade (TBD)



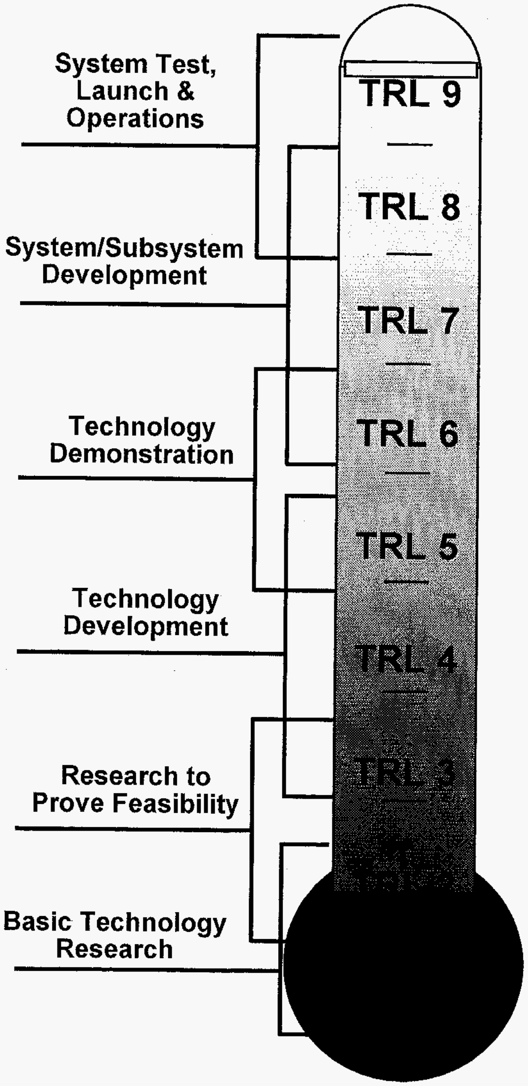
Technology Readiness Levels



Technology Readiness Levels (TRL) are a systematic metric/measurement system that supports assessments of the maturity of a particular technology and the consistent comparison of maturity between different types of technology.

TRL was originally designed for traditional engineering programs with specific requirements and products.

Technology Readiness Levels



TRL 9: Actual system "flight proven" through successful mission operations

TRL 8: Actual system completed and "flight qualified" through test and demonstration (Ground or Flight)

TRL 7: System prototype demonstration in a space environment

TRL 6: System/subsystem model or prototype demonstration in a relevant environment (Ground or Space)

TRL 5: Component and/or breadboard validation in relevant environment

TRL 4: Component and/or breadboard validation in laboratory environment

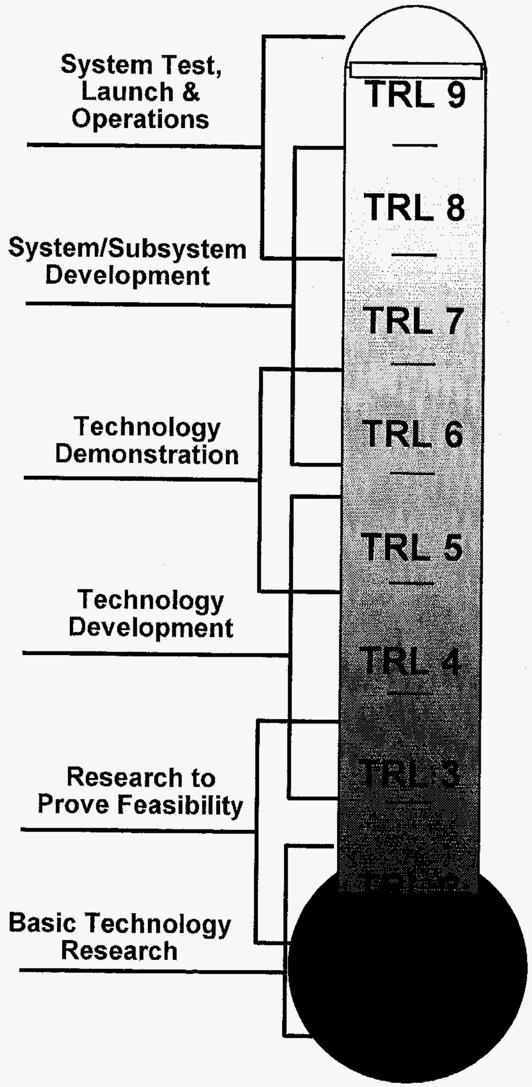
TRL 3: Analytical and experimental critical function and/or characteristic proof-of-concept

TRL 2: Technology concept and/or application formulated

TRL 1: Basic principles observed and reported

Technology Readiness Levels

Concept Applied to *Non-Flight* Planetary Protection Capabilities



TRL 9: Actual system "flight proven" through successful mission operations *(e.g., sample analysis during a mission shows that H2O2-treated surfaces are sterile.)*

TRL 8: Actual system completed and "flight qualified" through test and demonstration (Ground or Flight) *Demonstration of process integrity through further testing. (e.g., sample analysis shows that H2O2-treated surfaces on engineering model remained sterile.)*

TRL 7: System prototype demonstration in a space environment *Integration of procedure with assembly of an engineering model. (e.g., H2O2 integrated in the assembly of an engineering model.)*

TRL 6: System/subsystem model or prototype demonstration in a relevant environment (Ground or Space) *Integration of system with other ATLO procedures. (e.g., H2O2 tested on a subsystem and integrated with clean room procedures, etc.)*

TRL 5: Component and/or breadboard validation in relevant environment *Using representative parameters, development of protocol for candidate targets. (e.g., H2O2 sterilization protocol developed for electronics vs. optics vs. "outer skin" etc.) (*Note that I believe that NASA PPO review belongs here, not at TRL 8.)*

TRL 4: Component and/or breadboard validation in laboratory environment *Identification of relevant process parameters and mapping their effects on representative targets. (e.g., H2O2 sterilization tested at various concentrations, pressures, etc., on some candidate material - i.e., titanium, aluminum.)*

TRL 3: Analytical and experimental critical function and/or characteristic proof-of-concept *Preliminary testing of process on representative subsystem. (e.g., H2O2 vapor sterilizes titanium and aluminum coupons which have been pre-treated with the appropriate protocol.)*

TRL 2: Technology concept and/or application formulated *Identification of specific goal to be addressed in process design. (e.g., H2O2 vapor sterilization may be used to sterilize surfaces in the assembly process.)*

TRL 1: Basic principles observed and reported *Identification of principles to be used in designing processes. (e.g. exposure to H2O2 vapor leaves surfaces sterile.) .*

Technical Challenges for the Mars Program

- Enable sterilization at the system level
- Obtain improved knowledge of environmental effects on bioloads
  - Focused microbial diversity studies
  - Mars chamber development/utilization
  - Characterization of the limits of life
    - Laboratory simulations
    - Earth analogs
  - What is a "special region"
    - Define, assess, protect
- Avoid secondary contamination
- Prepare for human exploration of Mars

Summary

- Exploration of biologically interesting planets such as Mars (Europa, too) requires increased levels of capability in planetary protection.
- These capabilities require programs to focus on the broad challenges of planetary protection. Plans for forward and backward contamination control, returned sample handling, and the related area of organic contamination control have been formulated and are underway.
- The endeavor is inherently multidisciplinary, and requires the creative efforts of policy makers, planetary scientists, technologists, and systems engineers – as well as biologists.
- NASA and its international partners are actively engaged in planetary protection implementations for current missions, and in preparation for the very exciting missions of the future.
- Human space travel raises new issues and challenges. Planetary protection technology challenges will expand in the era of human exploration of Mars.