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Implementing Backwards Planetary Protection

A case-based approach to backward planetary protection compliance — from containment to Earth entry, descent and landing

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Clearance CL#25-4758

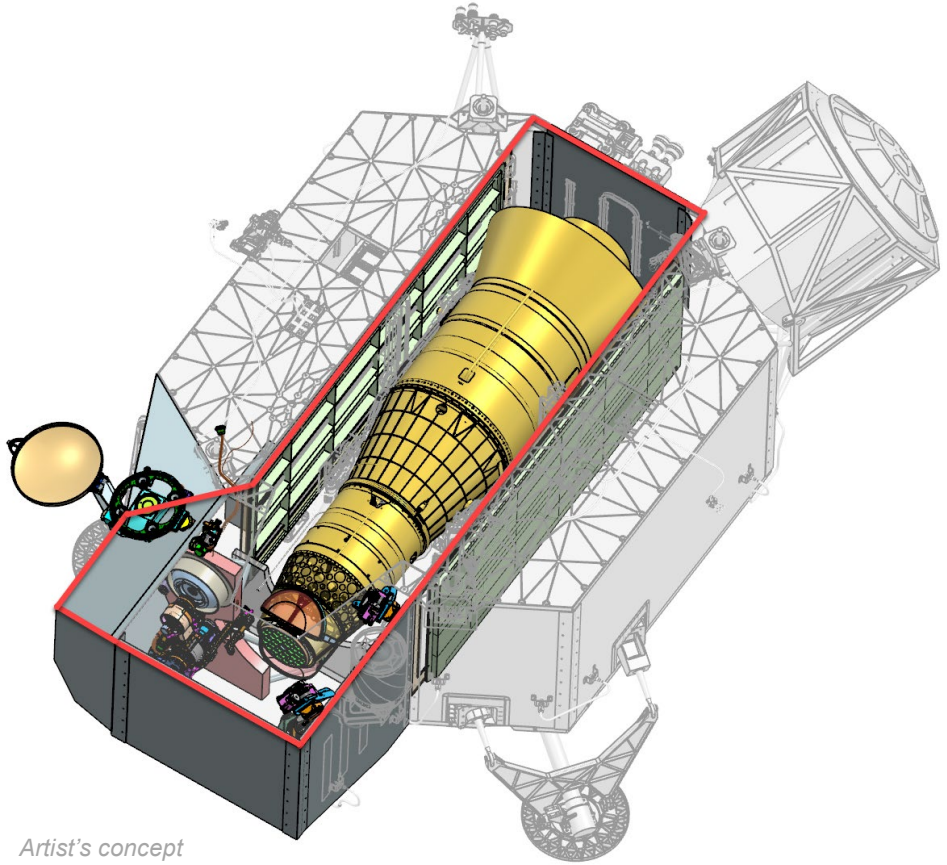
Presentation overview

Goal

- Illustrate two unique aspects of Planetary Protection (PP) for a restricted sample return, how to demonstrate sufficient safety and the timing of return approvals, using MSR's most recent compliance approach

Content

- Brief background on backward PP
- Basis and details of MSR's BPP compliance approach, including how it fits into the standard, pre-launch approvals common to recent missions
- MSR's plan* for return approvals and how mission design drives the approach



Artist's concept

Recent Sample Retrieval Lander (SRL) design highlighting the Hygienically Encapsulated Assembly (HygEA) which breaks the chain of contact with Earth before the samples reach Mars orbit*

**The decision to implement the Mars Sample Return Program or the Sample Retrieval Lander will not be finalized until NASA's completion of the National Environmental Policy Act (NEPA) process.*

Backward Planetary Protection considerations for sample returns

- Backward Planetary Protection (BPP) measures are designed to protect Earth's biosphere during sample returns from *potentially* hazardous target-body material
- Missions returning material to Earth are classified as Category V (Cat. V) unrestricted or restricted based on target's potential to host extant biology
  - Missions are categorized as Unrestricted if scientific consensus holds that the target body has no potential for active biology and no BPP measures are required
  - All other targets are Restricted Earth Return (Cat. Vr) and missions must implement BPP measures that ensure containment or sterilization of any material returned to Earth
- Cat. Vr missions have not been undertaken under the current NASA or COSPAR policies
  - The Apollo 11, 12 and 14 missions were performed under different, 'planetary quarantine', procedures
- Mars Sample Return planned as a joint NASA/ESA endeavor has been the most mature BPP approach to date
  - NASA and ESA developed extensive BPP flight hardware requirements and operations concepts
  - MSR submitted Program- and Project-level BPP requirements and preliminary implementation plans to NASA's Office of Planetary Protection
- The approach MSR identified for demonstrating compliance with NASA policies and the timeline for approval on the return leg are instructive for all future restricted sample returns

PP Compliance – from the process we know to gaining approval to safely return restricted samples

- Prior to launch, the BPP compliance process would be similar in cadence to outbound-only missions
  - Gate products (a.k.a., required documents) are defined in NASA policy and technical standards
  - PP reviews and gate product concurrences/approvals are performed alongside the standard life-cycle reviews up through launch
- Unlike outbound-only missions, the metrics used to demonstrate BPP compliance are more complex and cannot be assessed in full at launch
  - Cat. Vr missions inevitably require unique flight hardware functions and extremely high reliability standards
  - Key BPP steps are implemented *during* the mission: containment, breaking the chain of contact, sterilization, Earth impact avoidance
- BPP compliance reviews in the latter phases of a sample return mission may not be practicable
  - Return flights may be fly-bys with no opportunity to delay once initiated
  - Approaching delivery, mission-critical decision cycles are driven by a rapidly approaching spacecraft
  - Backup landing opportunities may be very limited (MSR plans include only two opportunities, 1.5 days apart)
  - Timelines to implement contingencies will be too short for formal review

MSR's proposed compliance approach during Earth delivery is a pathfinder for compliance assessment and assurance during a sample return

Applicable NASA Procedural Requirements provide the basis for MSR's approach and direction to address external review

NPR 8724.15; 9/24/2021

- §3.4.1 For missions conducting restricted sample return preventing harmful biological contamination of Earth's biosphere is the highest priority.

- §3.4.2 For each restricted sample return mission, the Mission Directorate Associate Administrator (MDAA) shall establish and implement a strategy and design concepts to break the chain of contact with the target body, isolate, and robustly contain restricted samples…

- §3.4.3 The process to assure the safety and containment of Earth-return samples should address:
  - Consideration of PD/NSC-25 and the Procedures for Implementing the National Environmental Policy Act (NEPA), 14 CFR § 1216.3.
  - Definition of an appropriate risk posture, comparative or otherwise, to inform decisions regarding the biological containment of returned samples.
  - Development, reporting, independent review, and acceptance by relevant authorities of an assurance case substantiating sufficient biological contamination control…

NASA's PP technical standards guide implementation and include a case-based compliance option

NASA STD 8719.24; 8/30/2022

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STD 8719.27 § 5.4.2

Category V(r) missions ***shall*** demonstrate avoidance of harmful contamination of the Earth-Moon System by release of one or more unsterilized particles into the Earth-Moon system of extraterrestrial material during all mission phases prior to Earth entry leveraging one or more of the following approaches, or a combination of them:

§ 5.4.2.a

An assessment that leverages strategies and design concepts that assure containment of target body-exposed Earth-return hardware factoring in the following:

§ 5.4.2.b

Sterilization and inactivation of samples prior to entry into the Earth-Moon System…

Potentially Undesirable

§ 5.4.2.c

Ensuring contaminated hardware or samples does not enter the Earth-Moon System.

Not Applicable to Returned Samples

§ 5.4.2.a.(a)

Likelihood of the presence of uncontained, unsterilized V(r) target material on the returning spacecraft hardware.

§ 5.4.2.a.(b)

Fidelity of mission design and diversion operations, including accuracy of delivery and impact avoidance at the Earth-Moon System of target-exposed spacecraft hardware within 100 years of initiation of Earth-return trajectory.

§ 5.4.2.a.(c)

Containment performance of the entry vehicle in the case of a nominal landing or capture.

§ 5.4.2.a.(d)

Potential for a credible off-nominal landing on the Earth or Moon surface or a failed in-space capture activity.

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§ 5.4.2.a
An assessment that leverages strategies and design concepts that assure containment of target body-exposed Earth-return hardware factoring in the following:

Plan: assert compliance in an assurance case that details a very low likelihood of uncontained material, redundant containment vessels engineered to function in highly unlikely landing states and measures taken to prevent such landings

§ 5.4.2.a.(a)
Likelihood of the presence of uncontained, unsterilized V(r) target material on the returning spacecraft hardware.

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Potential for a credible off-nominal landing on the Earth or Moon surface or a failed in-space capture activity.

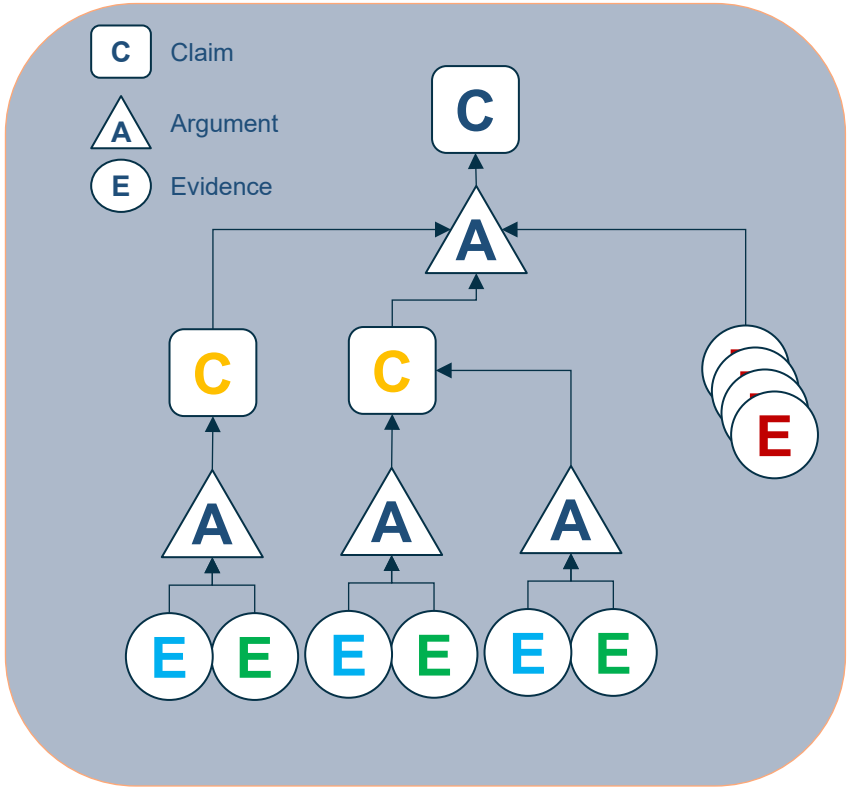
MSR developed proposed BPP Standards of Performance to link engineering requirements and the Assurance Case

- STD 8719.27 permits missions to demonstrate PP compliance through "An assessment that leverages strategies and design concepts that assure containment of target body-exposed Earth-return hardware" but does not specify an assurance level
  - NPR 8715.24 requires protecting Earth's biosphere be the highest priority
  - STD 8719.27 (§5.4.2a) notes that achieving an unsterilized extraterrestrial material release probability *"less than 1.0 x 10^{-6} for each phase"* is acceptable but not required
- MSR recognized that a probabilistic standard could not be implemented with high certainty across all phases
- Instead, MSR developed three Standards of Performance for its BPP assurance case and engineering requirements
  - Where analyses alone can be applied (i.e., particulate contamination vectors), MSR would demonstrate a very low likelihood of potentially harmful outcomes and address uncertainty with large margins (e.g., 10^{-8} probability of Mars material release)
  - Where physical containment measures can be implemented, MSR containment performance in credible off-nominal scenarios (e.g., selected, extreme landing cases with probabilities ≅10^{-6}) would be demonstrated through standard engineering
  - Systems that cannot meet these numeric standards due to fundamental limits (environments, mass constraints) MSR would prioritize BPP performance by using the Best Available Technology

    Best available technology is "the conclusion of a selection process in which several technological alternatives are evaluated accounting for factors related to technology readiness levels, launched mass limits, operational environments, and other mission parameters."
    – NASA Planetary Protection Handbook NASA/SP-20240016475 Version 1.0

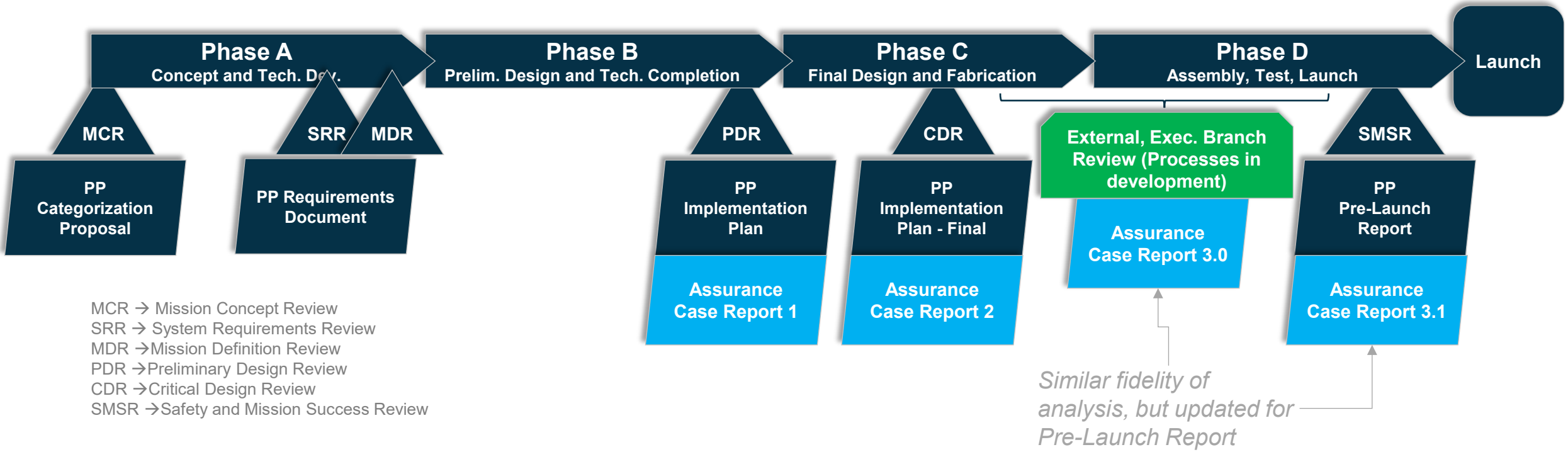
MSR's Assurance Case Structure: Accessible and ISO-standard

- Claims, Arguments, Evidence (CAE) is an accessible assurance case structure defined by ISO/IEC/IEEE
  - Tiered-source approach to making a Claim, where general statements are supported in tiers with detailed analyses/data
  - Potential for rapid, intuitive uptake by non-technical reviewers
  - Permits the use of qualitative and quantitative data as Evidence in support of Arguments
- The top-level claim would assert that the sample return is sufficiently safe with respect to avoiding contamination of Earth's biosphere with potential Mars biology
- Engineering and science data would provide qualitative information on the potential hazard(s) and the suitability of the overall approach
- The second-tier *claims* would reflect key BPP requirements, "Break The Chain of Contact at Mars" and "Contain through Landing"
- Testing and analyses that verify engineering requirements prior to launch, combined with in-flight telemetry confirming performance, would provide the *evidence* that one of the three standards has been met



The Assurance Case augments the standard PP launch approval process

- NASA internal processes utilize a standard set of ”gate product” documents to support key reviews
- Cat. Vr missions would demonstrate key capabilities prior to launch and a feasible path to implementing BPP measures in flight
- MSR would document these in BPP Assurance Case
  - Material containment, navigation and hazard avoidance leading to successful entry, descent and landing
- Assurance Case reports would be provided at key points, detailing completed work and analyses
- External review, likely as part of satisfying Presidential Directive NSC-25, could occur between CDR and SMSR



MSR proposed approach: *complete return approvals before leaving Mars*

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Interplanetary Transit Phase

- **BPP-relevant metrics like trajectory performance and spacecraft health updated regularly**
- **Anomaly responses would be as agreed in return approval reviews and Assurance Case**

ERO leaves Mars orbit, committed to Earth return and a specific delivery date

~11 months

~11 months

ERO captures the OS and begins to spiral up in Mars orbit

The e… orbit,

Samp… L…

Spiral Up Phase

- **All containment activity is finished**
- **ERO could wait in Mars orbit for a future return window *but is committed to a single Earth delivery phase upon leaving***
- **Assurance Case is updated and return approval/review would be completed *before leaving Mars orbit***
- **Thereafter, permission to proceed would be contingent on maintaining/achieving key metrics**

ERO performs the Earth Targeting Maneuver

4 or 5.5 days

ERO releases the Earth Entry System

ERO diverts away from Earth

3 or 1.5 days

Earth Entry System lands

Earth Delivery Phase

- **Activity cadence is high and decision timelines are short; decisions-to-proceed must be based on conditional agreements made before initiating the return.**
- **Two entry vehicle release options, 1.5 days apart**
- ***No-go for release = sample return failure***

Earth Return Orbiter (ERO) launches to Mars

Sample Retrieval Lander (SRL) launches to Mars, carrying an Orbiting Sample container (OS)

Earth Delivery Phase activity cadence is high

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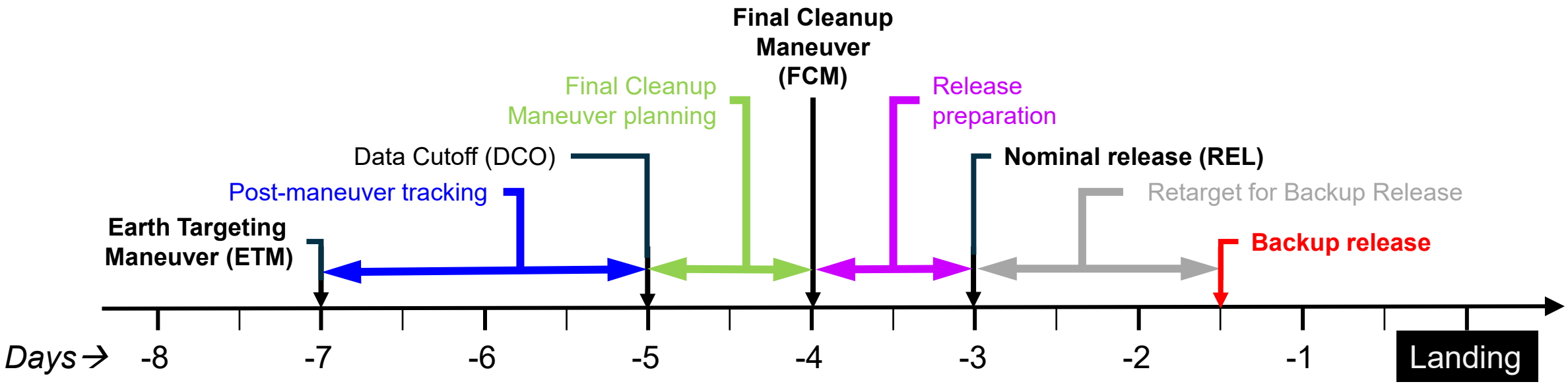
During MSR's planned delivery, the spacecraft is moving at ~12 km/s and decision timelines are compressed



Activity	From	To	Nominal Timeline	Compressed Timeline
Post-ETM tracking	ETM	DCO	2 days	1.5 days
FCM planning	DCO	FCM	1 day	0.5 day
Release preparation	FCM	REL	1 day	2 hrs
Total	**ETM**	**REL**	**4 days**	**50 hrs**

Summary: restricted sample returns will benefit from tailored approaches to compliance *and* approval

- Restricted return approvals are novel; the next mission to perform a restricted return will be the first under current policies
- MSR identified an Assurance Case-based approach to compliance from the options available in NASA's PP policies for Cat. V Restricted Returns
  - High standards of performance were proposed and applied to BPP engineering requirements
  - Using a standardized Assurance Case format provides an accessible compliance artifact readily reviewed by all stakeholders
- The MSR BPP Assurance Case would augment normal processes for PP compliance before launch and be updated with in-flight performance data to demonstrate readiness to return
- Return approval, as envisioned for for MSR, is best accomplished *before* the samples leave Mars orbit
  - Upon leaving Mars orbit, MSR would have two options: land on Earth on a specific date or aborting the mission and leaving the samples in orbit around the sun
  - During the return phase, timelines to implement contingency responses are too short for formal review – approval to proceed should specify conditions under which the mission is allowed to execute the return
- Cat. V restricted return authorization processes are still in development, the timing and nature of in-flight return approval should be tailored to fit each unique mission design

Thank you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