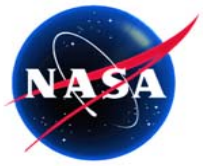

NEW MILLENNIUM PROGRAM

Mid-Technology Readiness Level Technology (TRL) Maturation Planning, TRL Criteria Setting and Assessment in Support of In-Space Technology Validation

2007 Technology Maturity Conference
Founders Inn, Virginia Beach, VA

Christopher M. Stevens
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September 12, 2007

Jet Propulsion Laboratory
California Institute of Technology

Report Documentation Page

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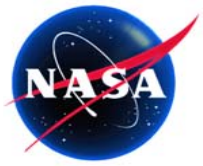


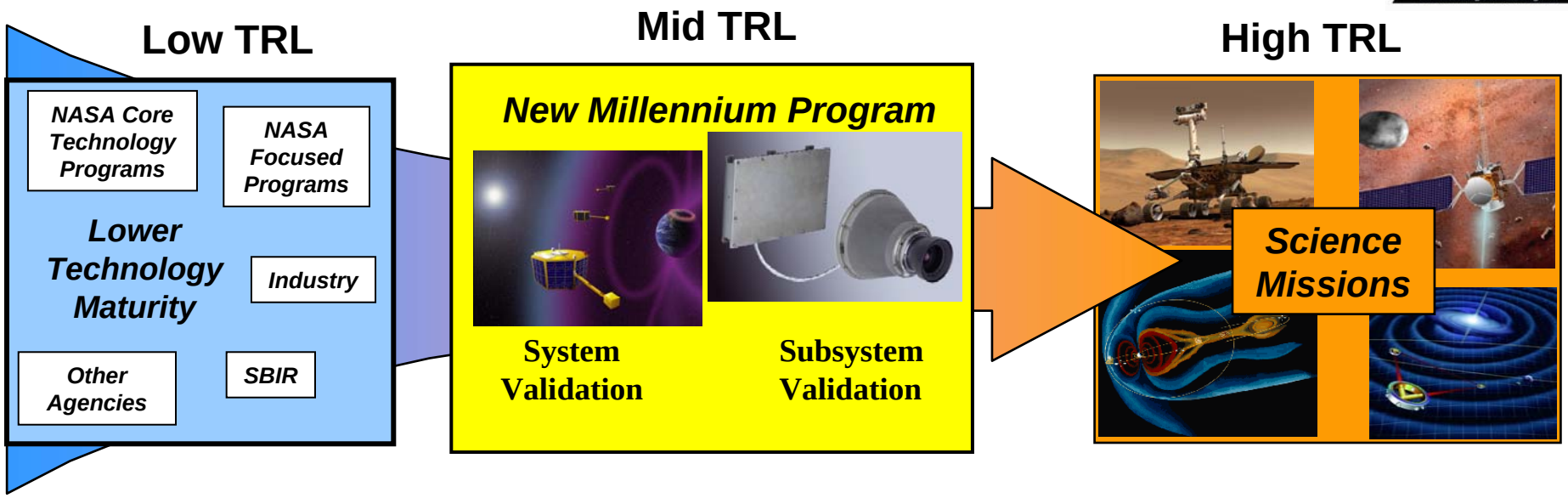
Discussion Points

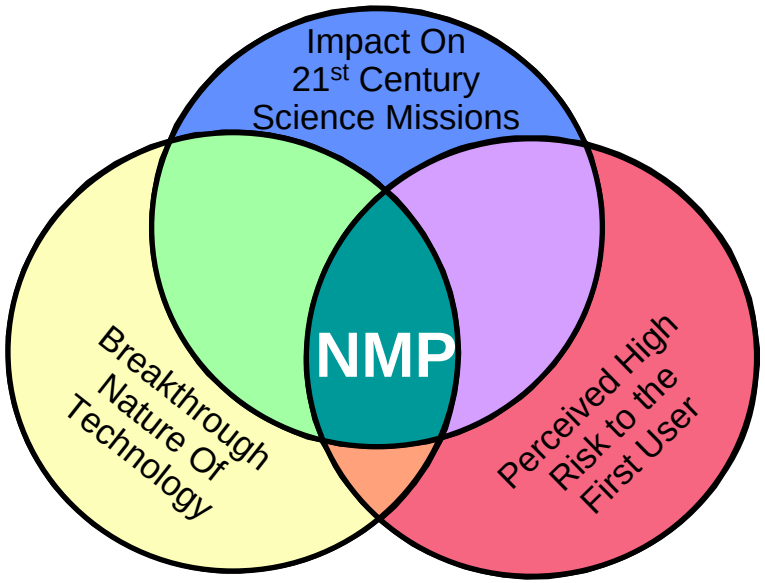
- **Introduction**
  - **Description of the New Millennium Program**
  - **Increasing technological maturity in a project environment**
  - **Approach to judging technological maturity**
- **NMP Approach to Assessing Technological Maturity**
  - **Guidelines**
  - **Mechanism for implementing guidelines**
- **Approach as applied to ST 8 and ST 9**
- **Summary**

Program Objectives and Purpose

- **Accelerate the incorporation of advanced technologies into future NASA science missions**
  - Derive needed capabilities and technical requirements from NASA science mission planning ("technology pull")
  - Conduct technology maturation and validation in low cost NMP project rather than during science mission development
  - Capitalize on investments being made in U.S technological capabilities
  - Provide infusion path with validated performance scalable to intended uses
    - Balance requirements/scope/cost to remain "affordable"
- **Focus on technologies ("breakthrough technologies") that will provide a significant (~order of magnitude) step forward in performance and/or reduction in cost**
  - Enable new capabilities to meet Earth and Space Science needs
  - Target technology capabilities that are broadly applicable to future needs
  - Reduce risk and costs of future missions
- **Select and mature advanced technologies for validation in the space environment, when flight validation is required to validate performance and reduce performance and development risks to the first users**
  - Objective is to validate the **technology advance**, not the widget
  - Intent is for technologies to have a much wider domain of applicability than the specific configuration flown

NMP Role





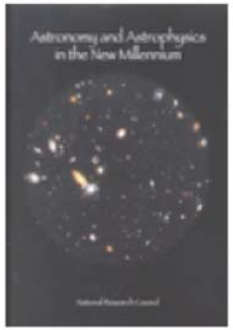
Breakthrough technologies

- Enable new capabilities to meet Earth and Space Science needs
- Reduce costs of future missions

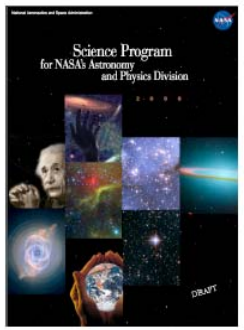
Flight validation

- Mitigates risks to first users
- Enables rapid technology infusion into future missions

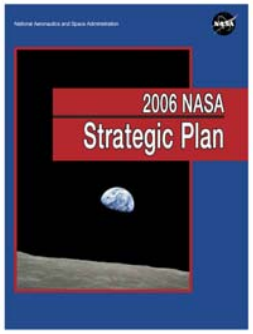
Science Planning Drives Technology Validation Needs



NRC Decadal Survey 2001



Community Roadmaps 2006



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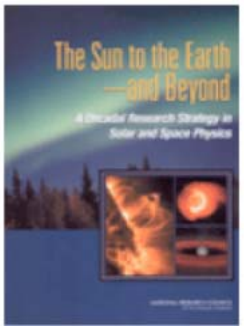
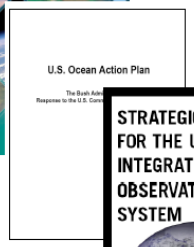
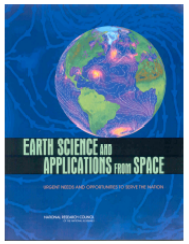


NRC Decadal Survey 2002



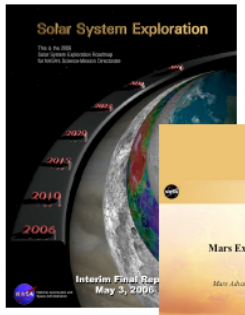


(Interim Report)

6 Science Focus Area roadmaps; yet to be integrated into a single Earth Science roadmap

2005

NRC Decadal Survey ~2007



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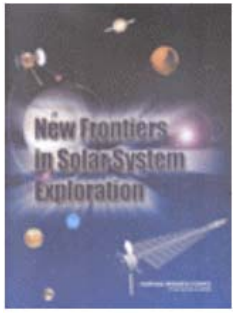
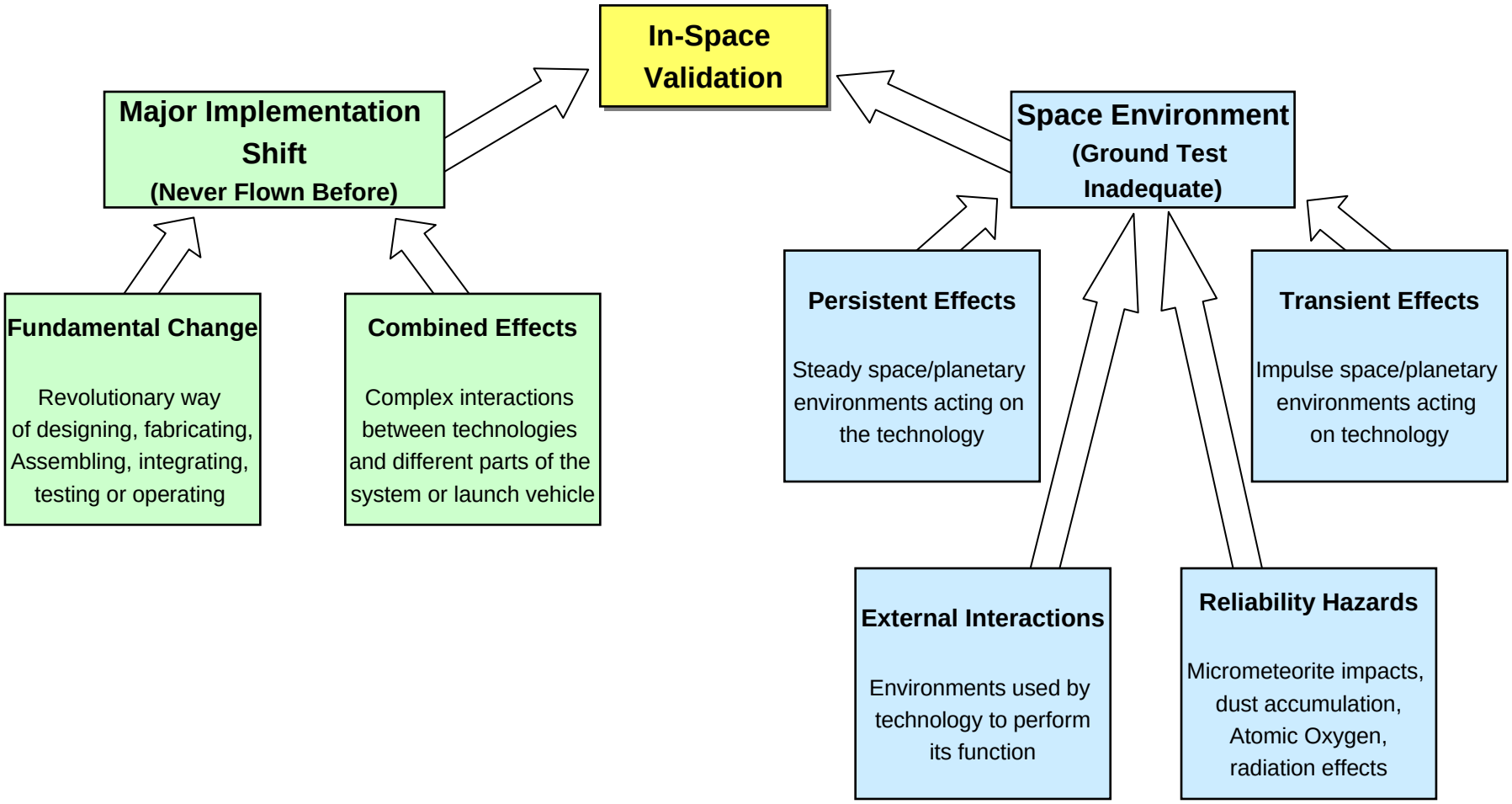


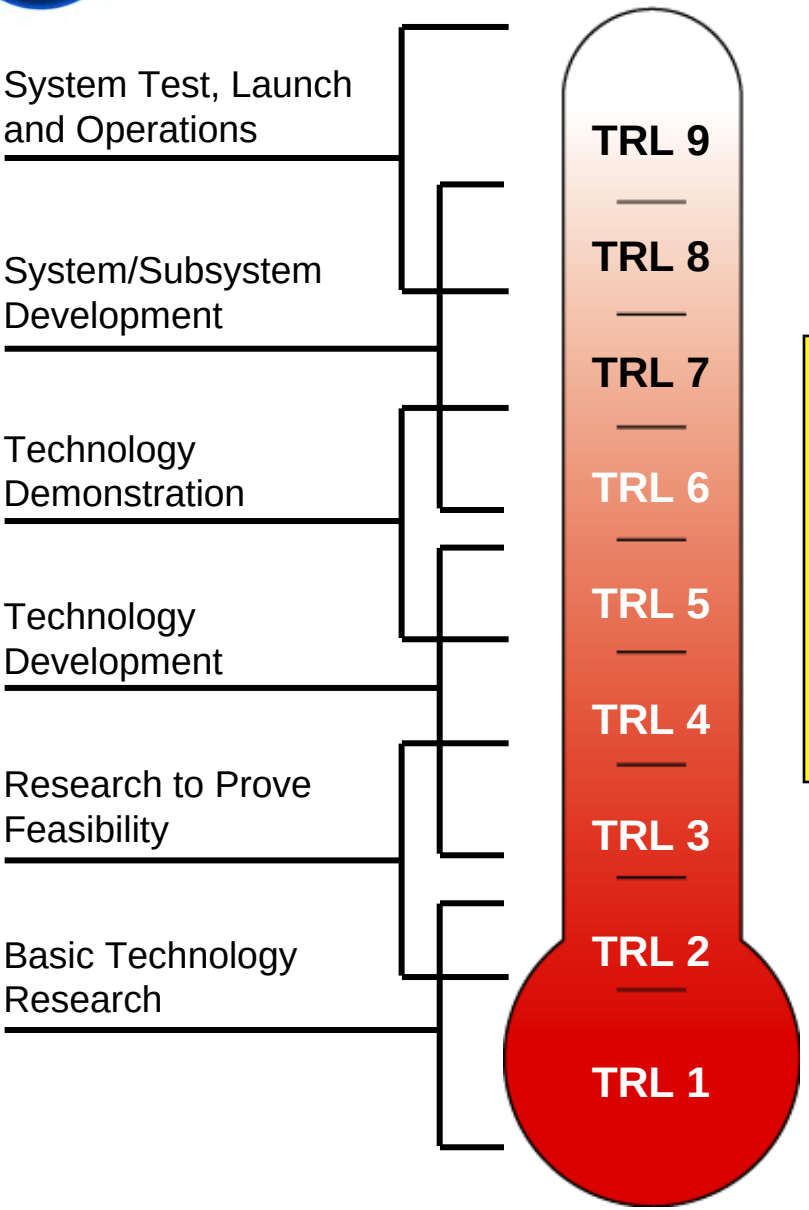
NRC Decadal Survey 2003

Flight Validation Criteria

Technologies to be validated in space must meet one or more of the NMP Flight Validation Criteria



New Millennium Program
Technology Readiness Levels (TRLs)



Actual system "flight proven" through successful mission operations

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

System prototype demonstration in a space environment

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

Component and/or breadboard validation in relevant environment

Component and/or breadboard validation in laboratory environment

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

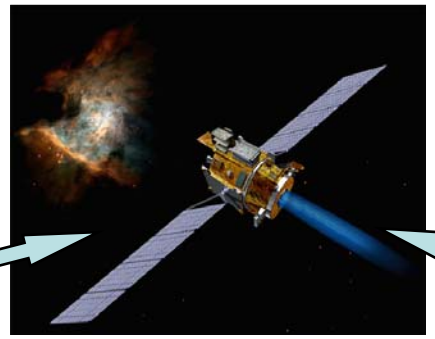
Technology concept and/or application formulated

Basic principles observed and reported

Validation Experiment Types

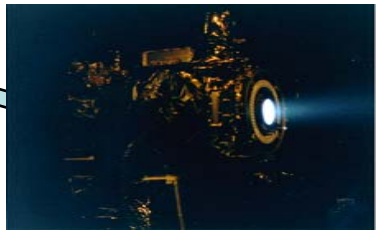
- System Validation:
  - **Combination of advanced technologies that are integrated into a system to validate a single technological capability:**
    - Solar Electric Propulsion – “Mission Defining”

Deep Space 1



SCARLET Array

Ion Engine

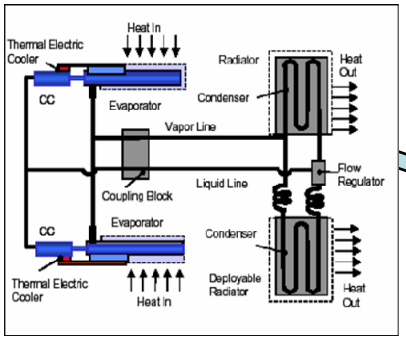


Validation Experiment Types

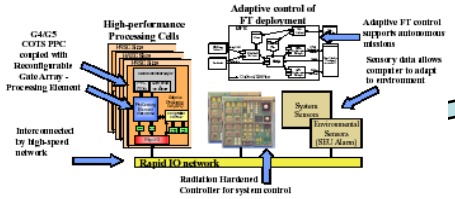
Subsystem:

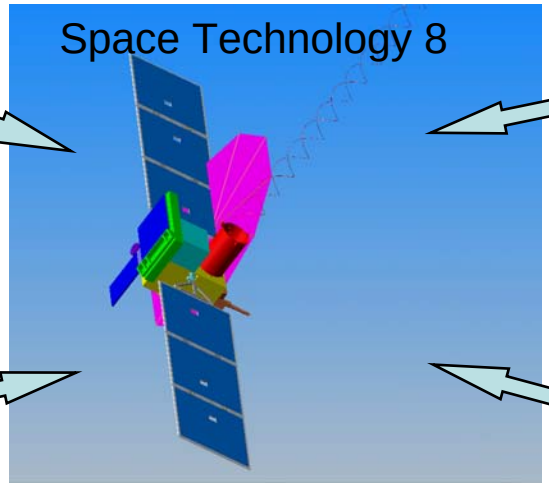
- Standalone subsystem experiment that can be flown as a payload on a variety of space-borne platforms
- Multiple experiments on single spacecraft not dependent upon each other for validation

Mini-Loop Heat Pipe

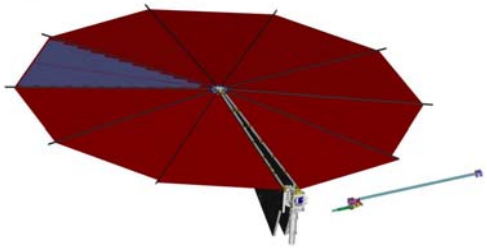


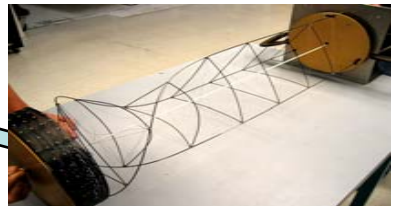
Env. Adaptive FT Computing





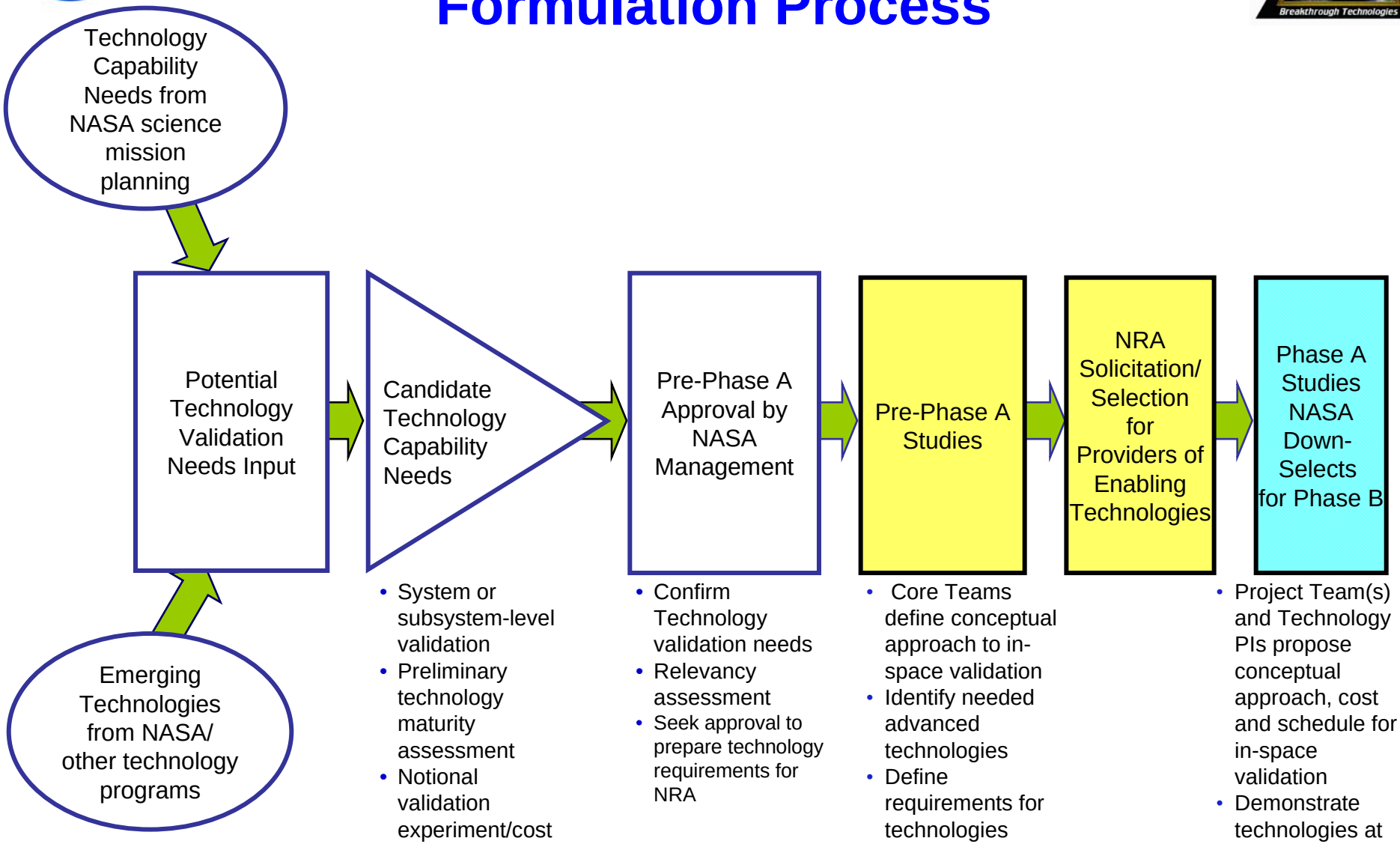
Next Gen. Ultraflex





Sailmast

Technology Validation Project Formulation Process



- System or subsystem-level validation
- Preliminary technology maturity assessment
- Notional validation experiment/cost range
- Rationale for flight validation

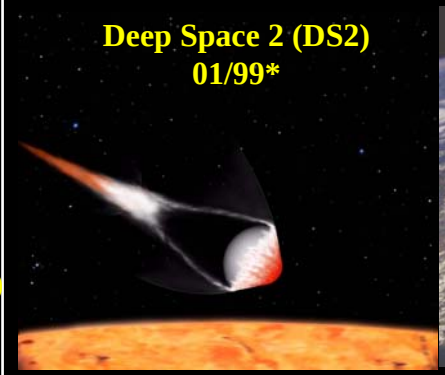
- Confirm Technology validation needs
- Relevancy assessment
- Seek approval to prepare technology requirements for NRA

- Core Teams define conceptual approach to in-space validation
- Identify needed advanced technologies
- Define requirements for technologies

- Project Team(s) and Technology PIs propose conceptual approach, cost and schedule for in-space validation
- Demonstrate technologies at TRL 4

Program Overview

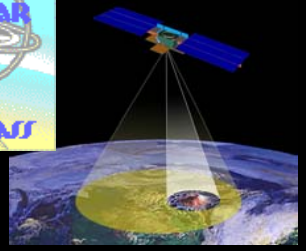
Deep Space 1 (DS1)
10/98*



Deep Space 2 (DS2)
01/99*

Earth Orbiting 1 (EO1)
11/00*

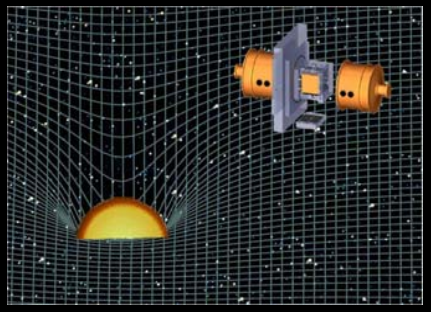
Space Technology 5 (ST5)
03/06*



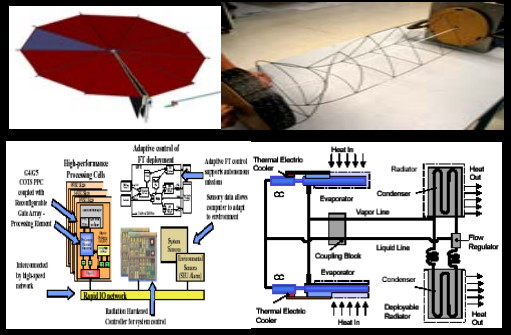
12/06*

12/03*

Space Technology 6 (ST6)



Disturbance Reduction System
Space Technology 7 (ST7)
2009



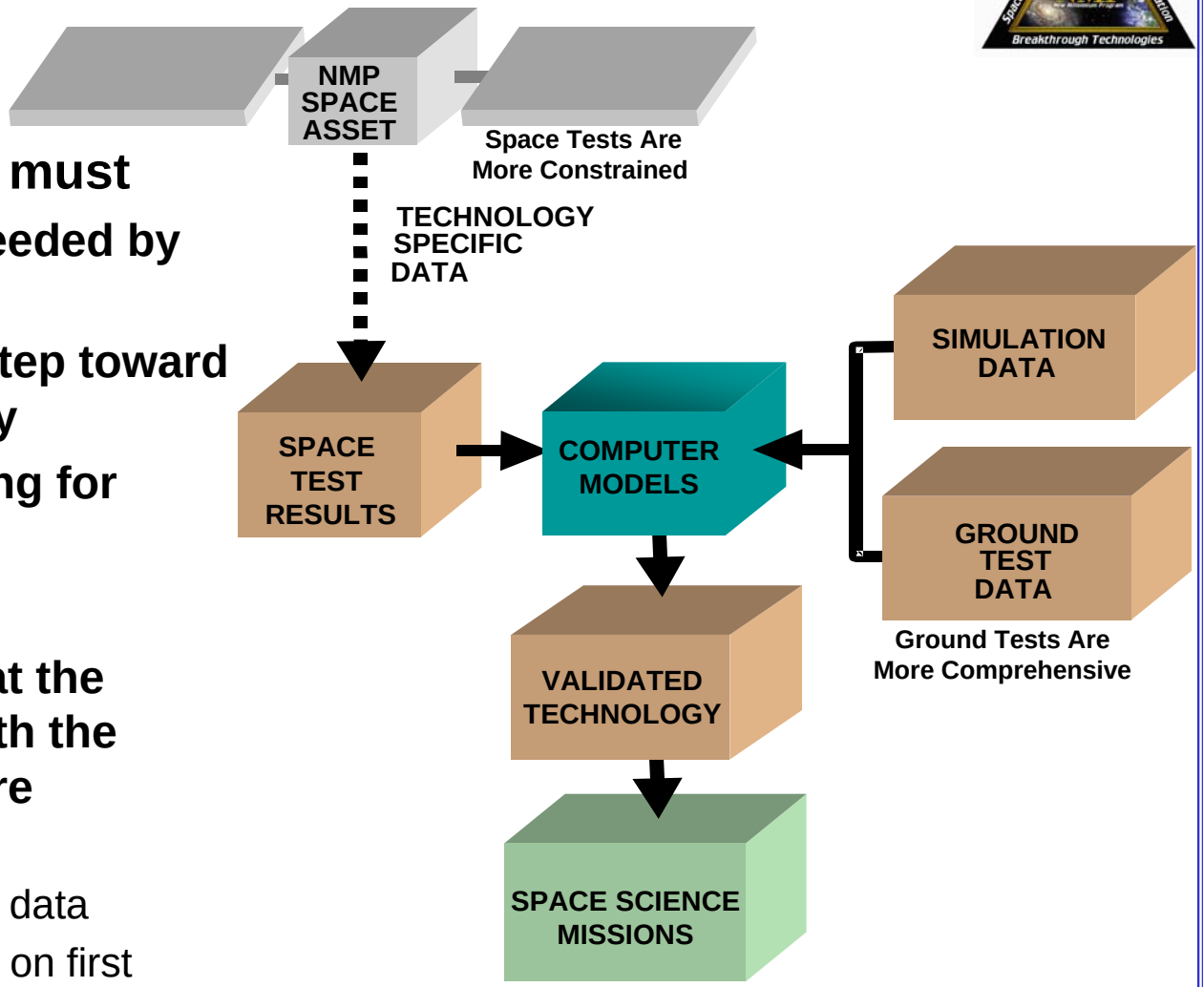
Space Technology 8 (ST8)
2009

Space Technology 9 (ST9)
2010

* Actual Launch Date

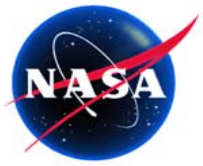
Validation of a Technology Advance

- **Technology Advances must**
  - **Provide a capability needed by NASA**
  - **Provide a significant step toward realizing that capability**
  - **Require in-space testing for proper validation**
- **Validation is**
  - **Empirical evidence that the physics associated with the technology advance are understood**
    - Empirical evidence: test data
    - Physics: a model based on first principles
    - Understanding: model's ability to replicate/predict test results



Technological Maturity Requirements

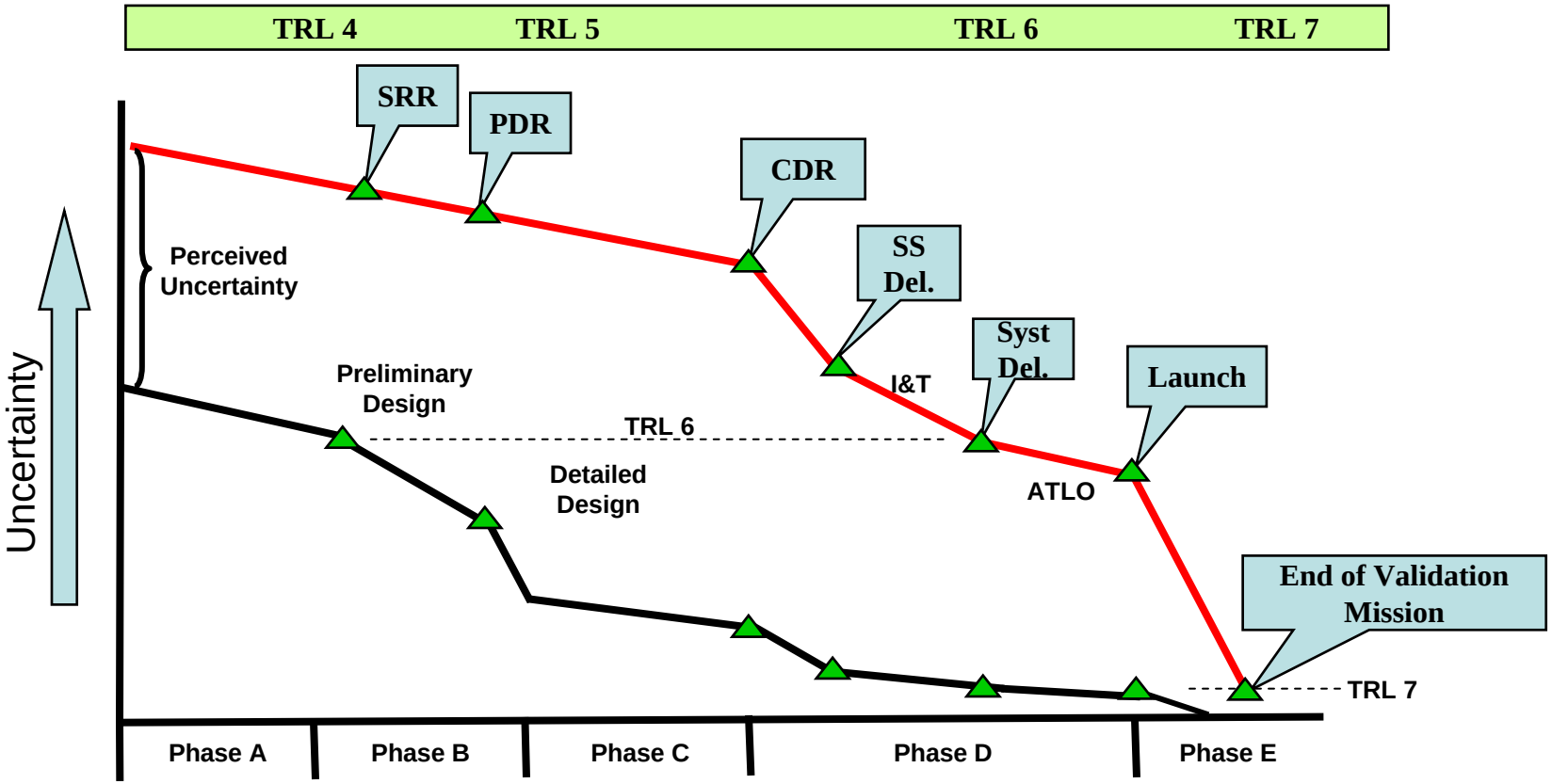
- **NMP projects are flight missions**
  - **Candidate technology advances must be at TRL ≥ 4 at start of Phase B**
  - **Technology maturation plan is part of evaluation for selection for Phase B**
  - **Technologies must reach maturity = TRL 6 by start of start of system assembly, test and launch operations (ATLO)**
- **Increasing technological maturity in the project development environment is a defining element of NMP projects**
  - **Required level of maturity for each stage must be defined**
  - **Fair, well understood criteria for determining the level of maturity must be defined**
  - **An objective method for assessing the degree to which the criteria have been satisfied must be established and implemented**
- **NMP is strongly motivated to establish meaningful and realistic technology-specific criteria by which to judge the maturity of a technology advance**



Cost and Schedule Risk

- **NMP missions are cost constrained**
  - **Acute sensitivity to project cost and schedule risk must be maintained throughout an NMP project**
  - **Risk-based cost and schedule reserves are required at Phase A-B transition and at project Confirmation (start of Phase C)**
  - **Proceeding to a subsequent project development phase before the technologies are sufficiently mature places the project at high cost and schedule risk and project reserves are likely to be exceeded**
    - Leads to a reduction in scope of the validation experiment and reduces the value of the project to NASA

Technical, Cost and Schedule Risks in Project Lifecycles

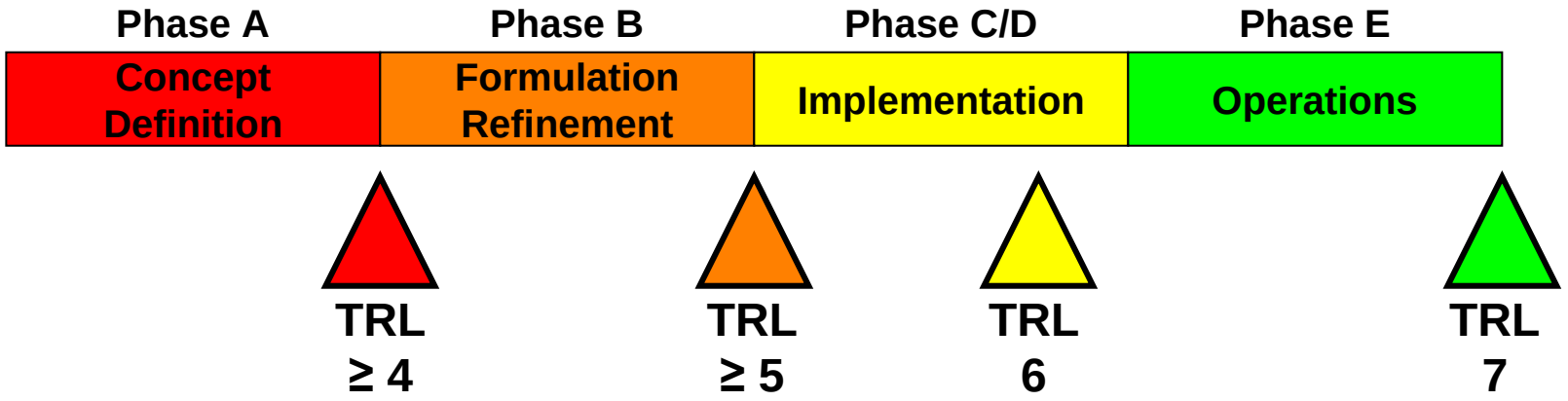


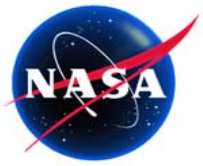
Project Lifecycle

Increasing Technological Maturity in a Project Environment

The risk of spiraling cost growth associated with maturing a technology advance in a New Millennium project is mitigated by defining clearly at the outset:

- **The capability to be put in place based on the needs of future SMD science missions**
- **The technology advance that can provide the capability**
- **The level of maturity to be achieved by that technology advance at each stage of the project**





NMP's Approach to Assessing Technological Maturity Begins with Guidelines

Guidelines

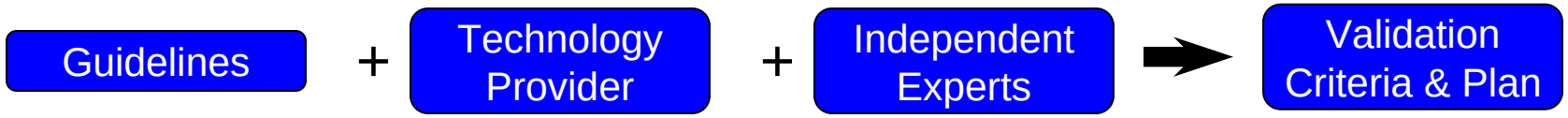
- **Establish general criteria for technological maturity at each TRL**
  - Provides broad uniformity across the program
- **Assess Technological Maturity in Three Areas**
  - Configuration: increasing maturity approaches that of a flight system
  - Models: increased fidelity and complexity indicates higher maturity
  - Test environments: greater realism that increasingly stresses the technology advance demonstrates greater maturity
- **Leave some elements of each criteria undefined**
  - Specific test article
  - Degree of model fidelity
  - Specific test environment

Assessing Technological Maturity Requires Clear Criteria

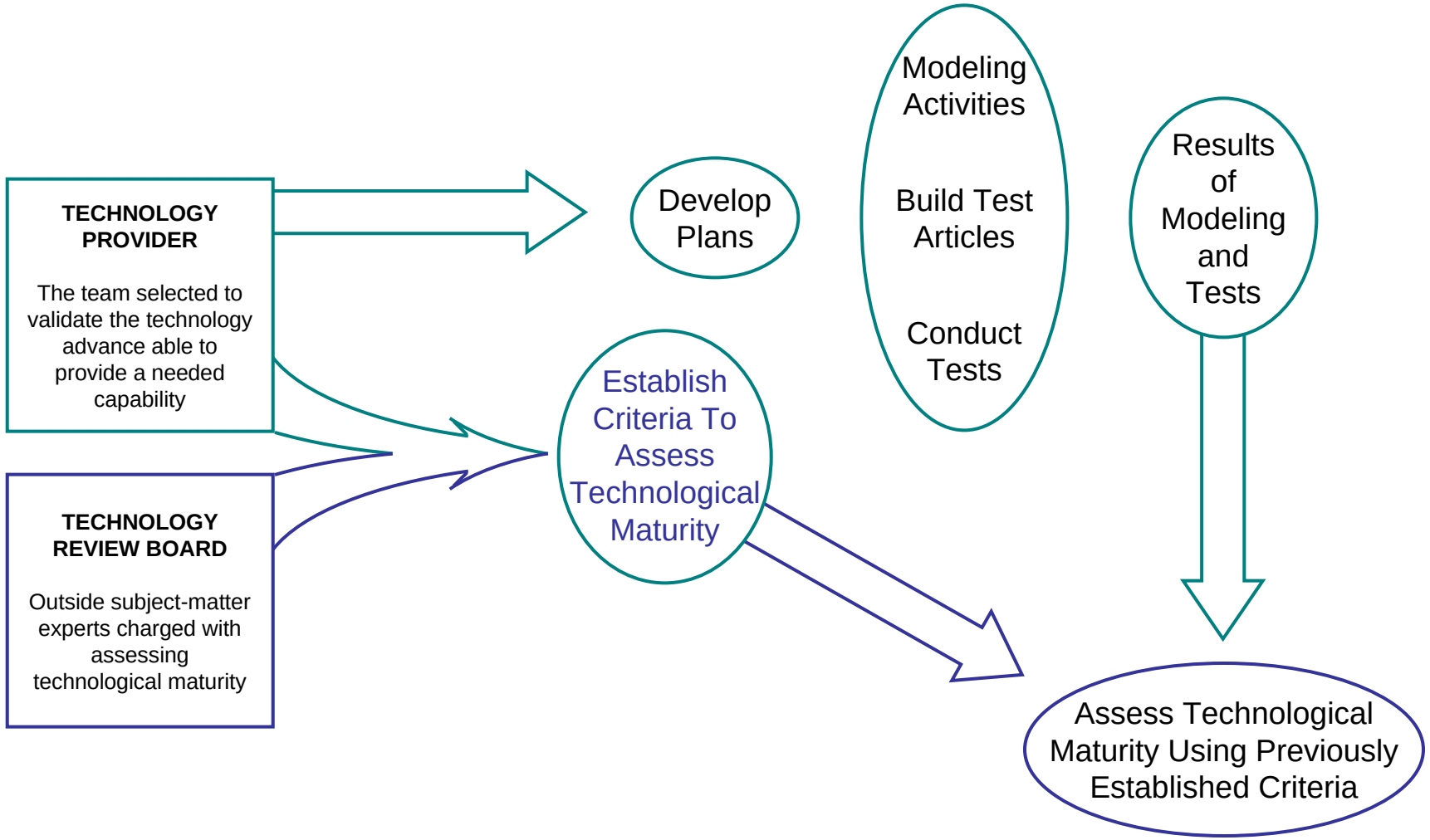
- **NMP employs the TRLs as a "measure" of technological maturity**
- **Criteria are developed that allow maturity to be assessed as the project unfolds**
  - **Developed as a joint activity by the provider of the technology advance, the project, and the program office**
  - **Developed early in the project to allow adequate planning**
  - **Revisited throughout the project's life to allow for exogenous changes**
  - **Are appropriate to the associated project phase to prevent the project from incurring unwarranted risk**
    - NMP Projects invest relatively heavily in Phases A & B
- **Assessment process must be, and be seen to be, objective and equitable**

Technology Review Board (TRB)
Jointly Develops Assessment Criteria and Assesses Technological Maturity

- **Assessment by team of independent, subject-matter experts selected for each technology advance**
  - **Specific criteria established early**
    - Based on the guidelines as a starting point
    - Developed jointly with the Technology Provider
    - Developed with the needs of the likely first user in mind
    - Used for schedule and budget planning
  - **Assessment based on jointly developed criteria**
- **Independent team provides flexibility while retaining focus on value**
  - **Responses to inevitable exogenous changes retain focus on value for the ultimate user**
    - Both Technology Provider and subject-matter experts are interested in successful validation

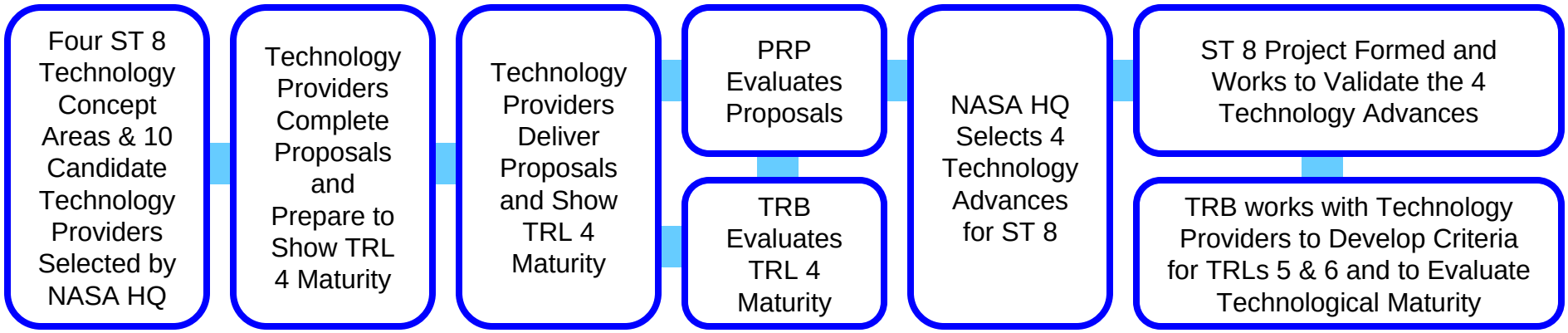


The Technology Provider and the Technology Review Board Work in Concert

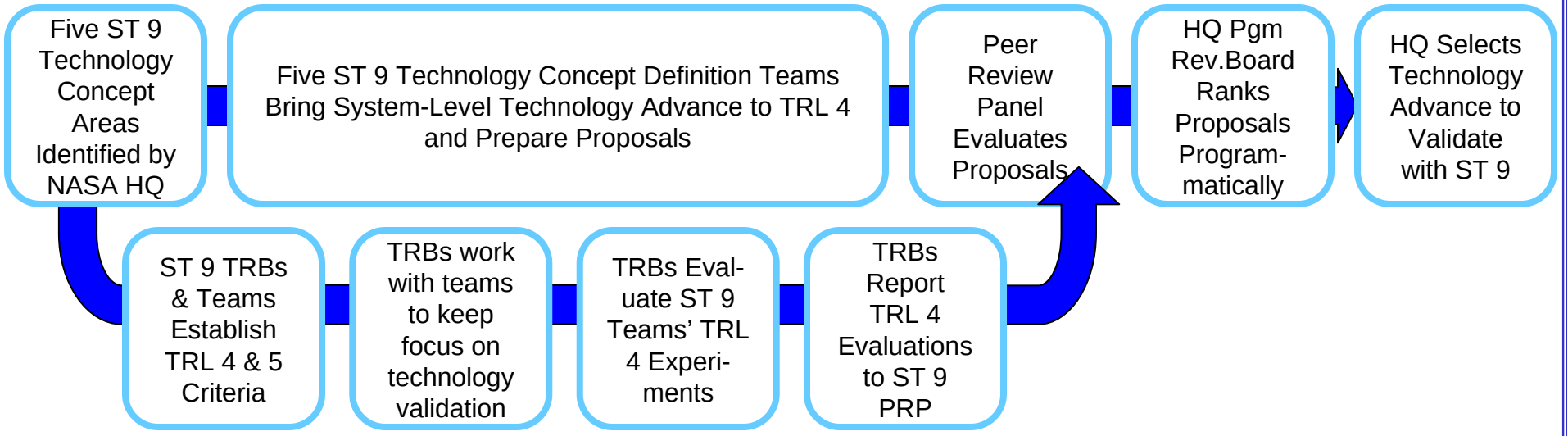


For ST8 & ST9 the TRB was Integral to Selection and Implementation

ST 8



ST 9



Summary

Key Points about NMP's Approach to Technology Maturation

- **Technology advances to be matured are selected in response to user-identified, needed capabilities**
- **New Millennium missions are a lower cost method of maturing these technology advances than doing so as part of a science mission**
- **Maturing the technology advance consists of**
  - **Test articles of continuously increasing fidelity**
  - **Test environments and tests that increasingly stress the technology advance**
  - **Models of the technology advance that replicate the test data**
- **Clear guidelines identify what is expected**
- **Independent experts work with the technology provider to identify mutually acceptable criteria for assessing the maturity of the technology advance**