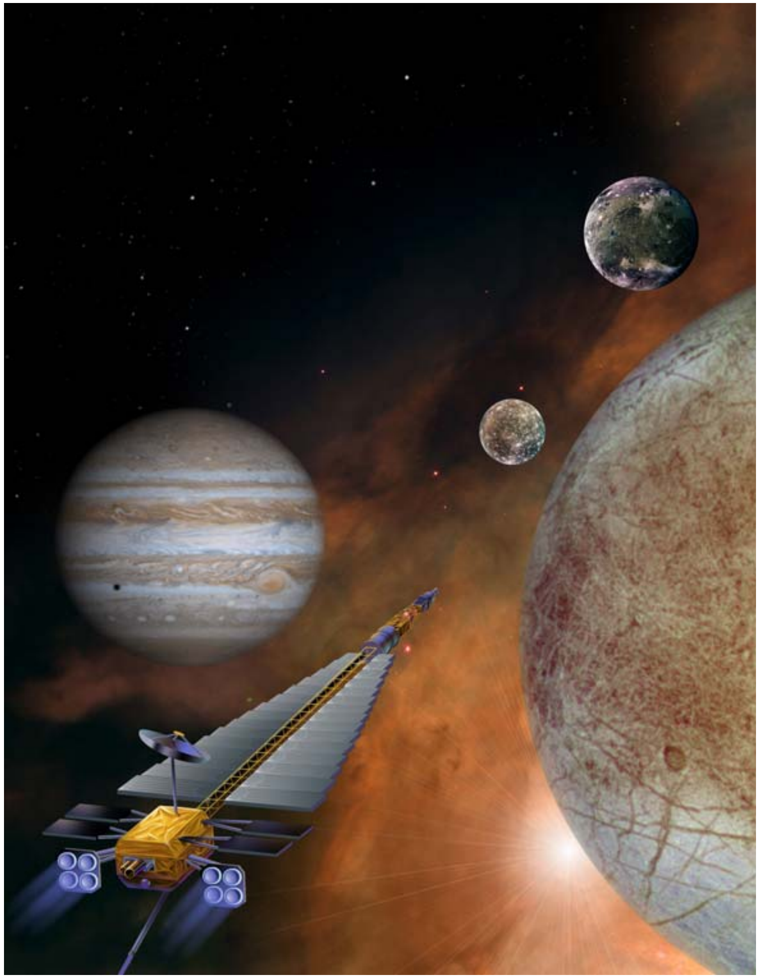

Exploring the habitable Water worlds of Jupiter – Callisto, Ganymede and Europa

"Risk Management in a Technology Driven Environment"

Presented at: NASA's Risk Management Conference 2004

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For

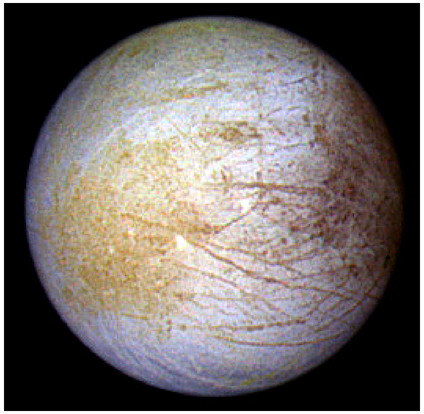
John Casani

October 26, 2004

Mission Description

- The Prometheus 1 Jupiter Icy Moons Orbiter (JIMO) mission responds to the National Academy of Sciences' recommendation that a Europa orbiter mission be the number one priority for a flagship mission in Solar System exploration
- JIMO will search for evidence of global subsurface oceans on Jupiter's three icy moons: Europa, Ganymede, and Callisto.
- JIMO will be the first flight mission to use fission nuclear power and propulsion technologies.
- This mission will set the stage for the next phase of exploring Jupiter and will open the rest of the outer Solar System to detailed exploration.

Science Background



- Europa, Ganymede, and Callisto very likely have global liquid water oceans beneath their icy crusts.

  …one of the major discoveries in solar system science in the last decade.

- There is spectral evidence for salts and organic materials on their surfaces, and geologic evidence that the Europan ocean may have been in contact with the surface in the geologically recent past (less than about 100 million years).

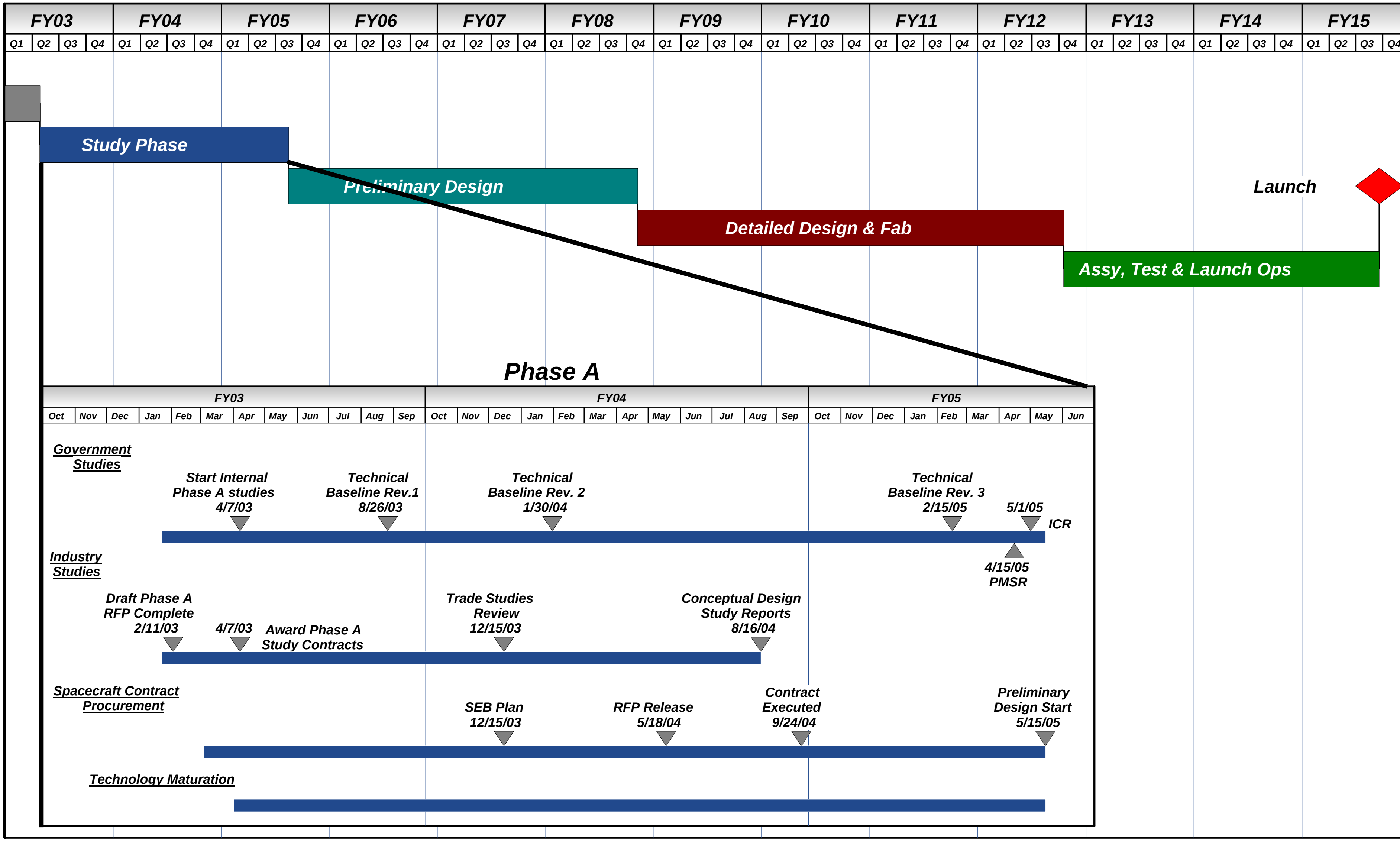
  … *these bodies are among the most exciting in the solar system for geophysical, geochemical and astrobiological exploration.*

Strongly responsive to the Nat'l Academy of Sciences priorities: **Europa Orbiter was 1st priority flagship mission in Decadal Survey of solar system exploration**

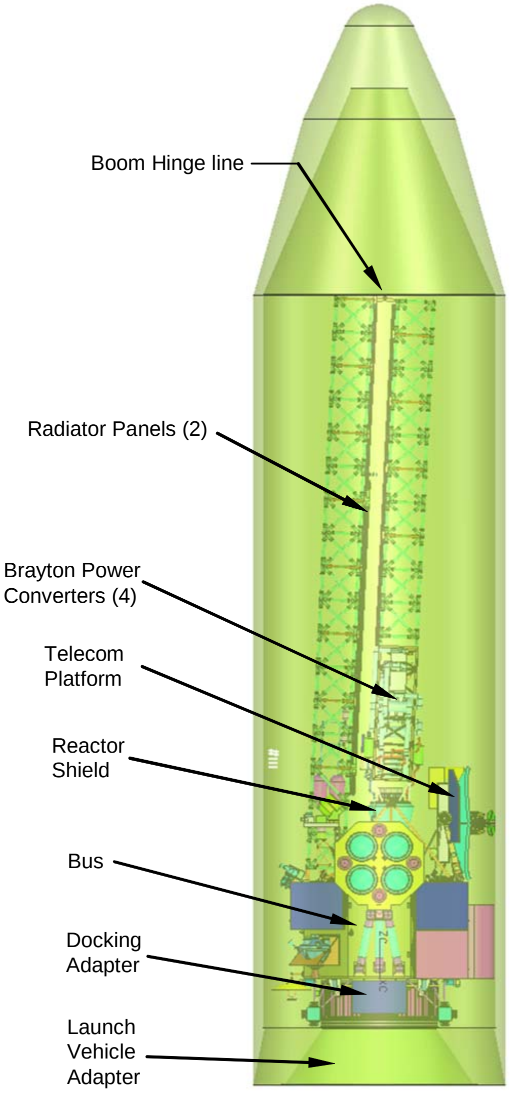
JIMO Overarching Objectives

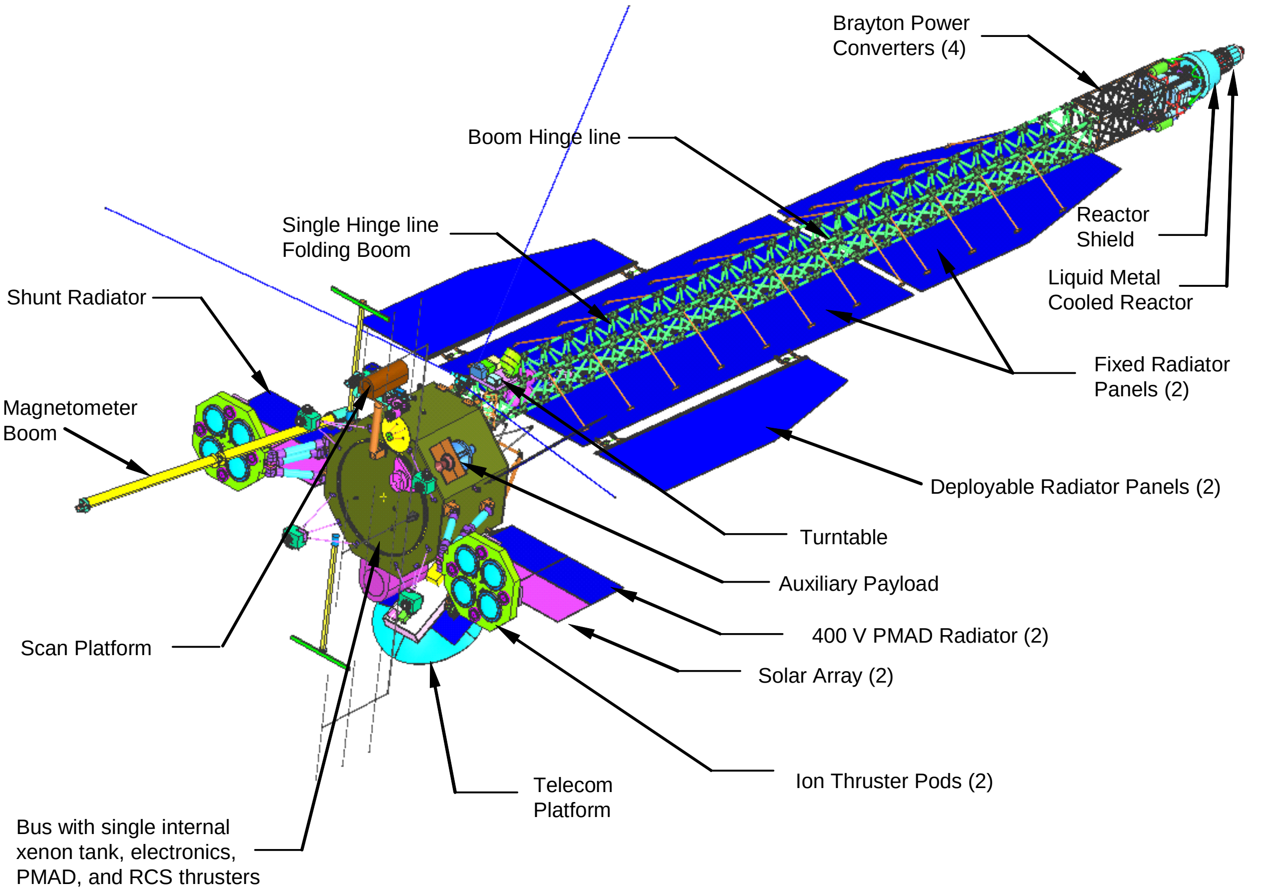
- Technology
  - Develop a nuclear reactor powered spacecraft and assure that it can be processed, launched, and operated safely and reliably in deep space for long-duration deep space exploration
- Science
  - Explore the three icy moons of Jupiter – Callisto, Ganymede, and Europa -and return science data that will meet the highest scientific goals as set forth in the Decadal Survey Report of the National Academy of Sciences.
- Follow-on Missions
  - Developed technologies shall be designed as to be extensible to future Lunar and Mars missions

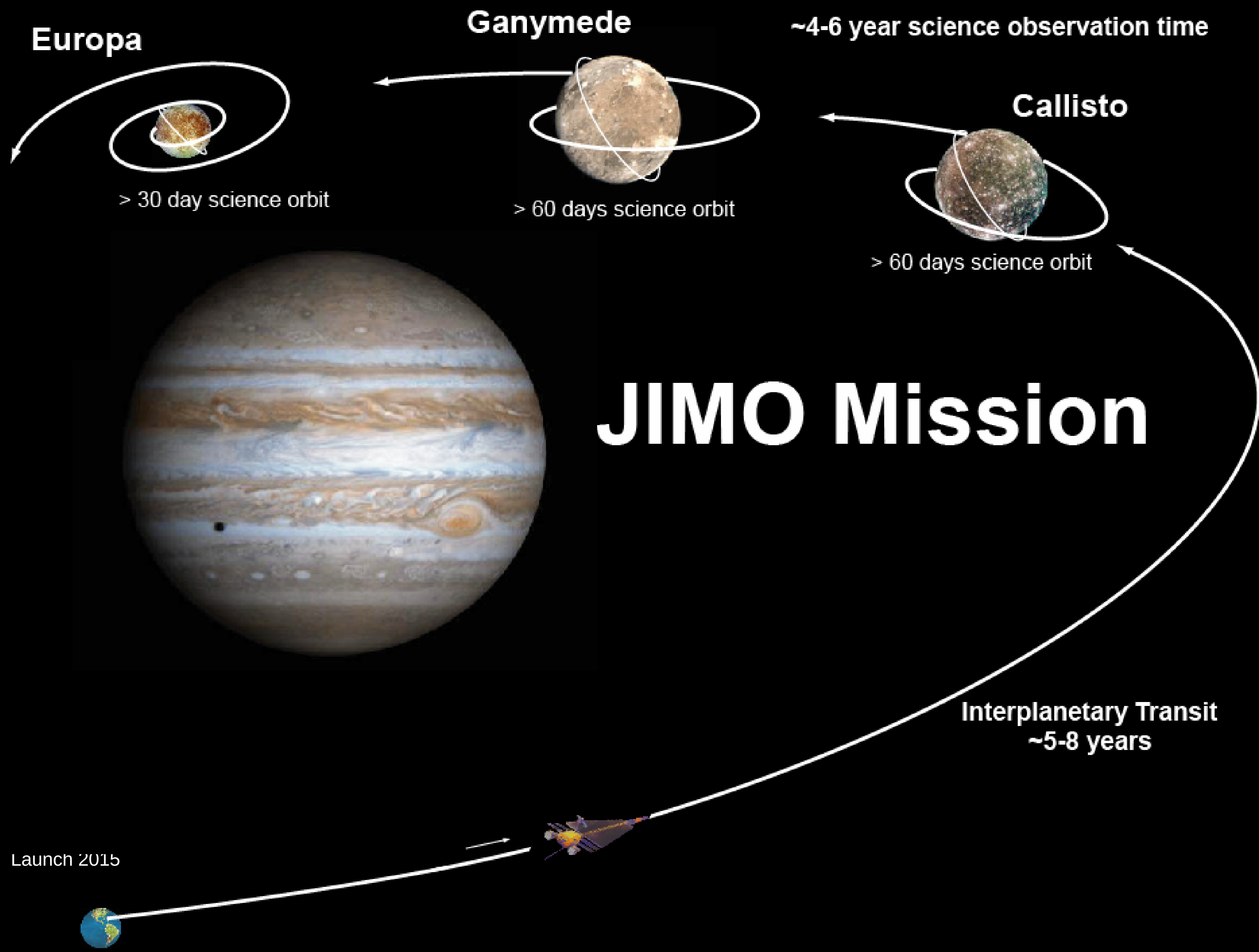
Project Development Schedule



Government Team TB2.5 Design







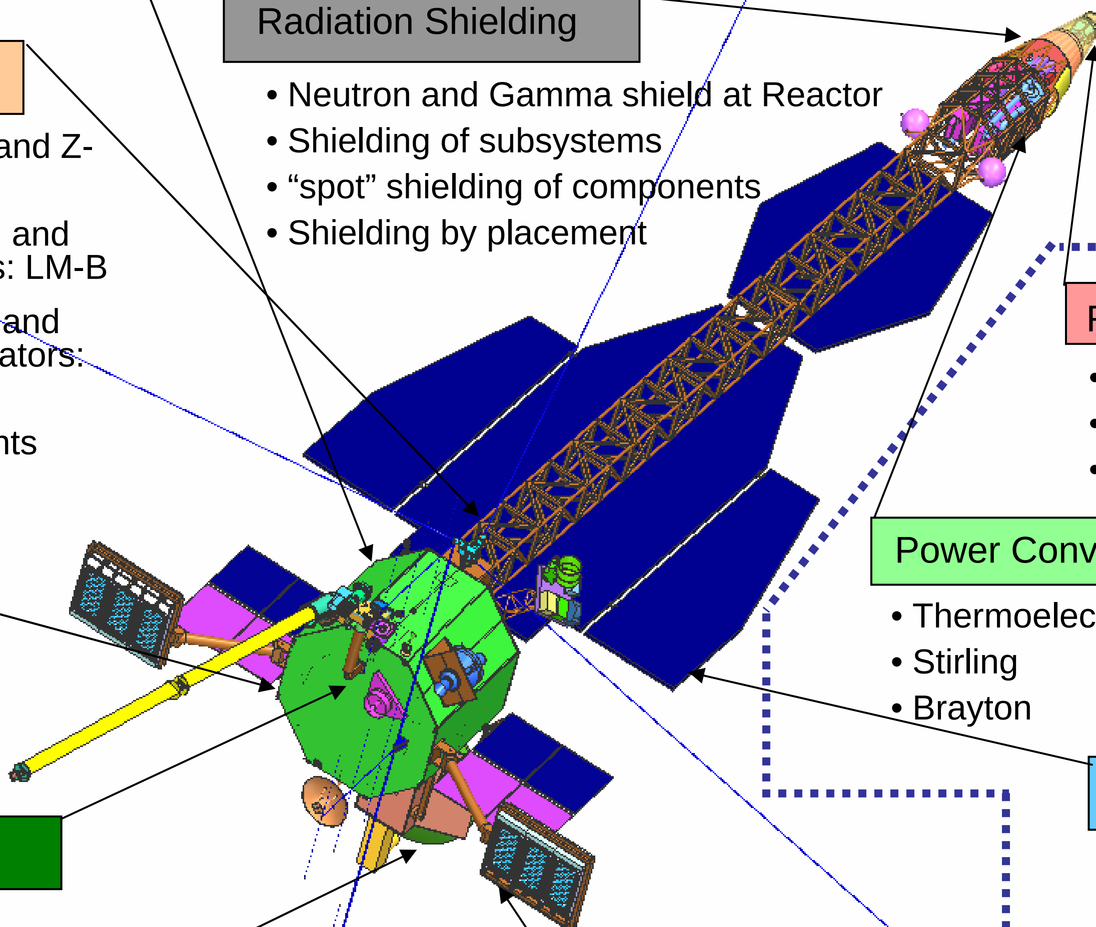
PRE-DECISIONAL – For internal administrative use only, not for release outside of the JIMO Government team.

Challenges for a Technology Driven Flight Project

- Establishing the right requirements
  - Definition of Requirements
  - Verification and validation
- Management of a large national team
  - Diverse Team
- Motivational differences between:

  "Technology Developers" and "Flight Project Implementers"
- Schedule Constraints
  - Bringing technologies to measurable states of maturity by PDR date.
  - Integrated schedule with critical path items and interfaces

Key Space System Trades



Boom Structure
- Telescoping Boom and Z-fold Radiators
- Single Hinge, Boom and Deployable Radiators: LM-B
- Single Hinge Boom and Non-deployable Radiators: LM-TE
- Fixed-no deployments

Radiation Shielding
- Neutron and Gamma shield at Reactor
- Shielding of subsystems
- “spot” shielding of components
- Shielding by placement

ACS-RCS
- Hydrazine
- Xenon
- Forward-Aft

P/L Accommodation

Telecommunications
- Klystron
- TWT

Electric Propulsion
- Ion Thruster
- Hall Thruster

Power Generation

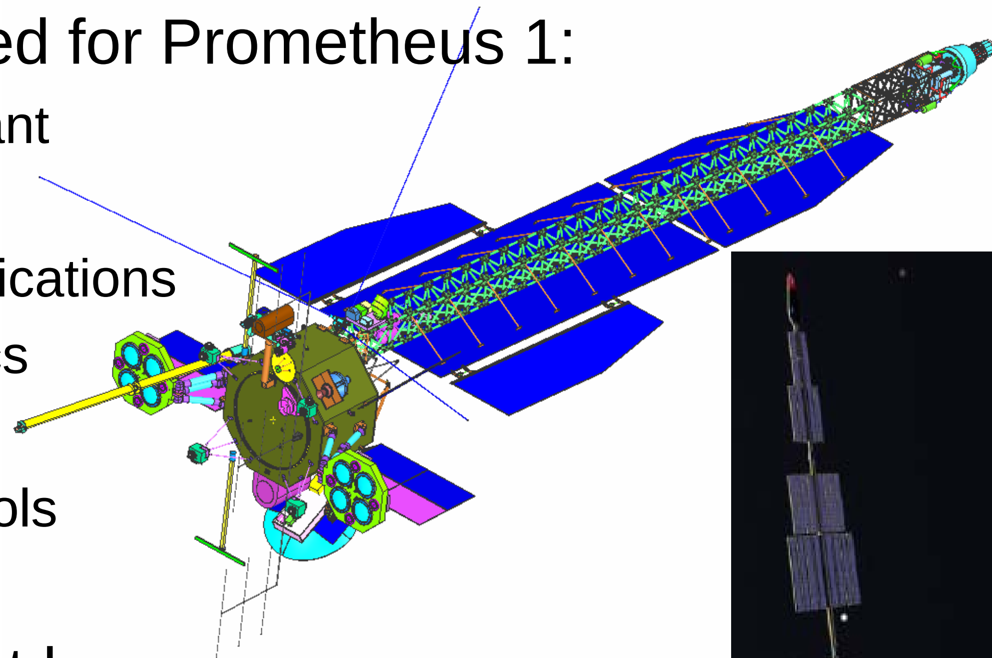
Reactor
- Heat pipe cooled
- Liquid metal cooled
- Gas cooled

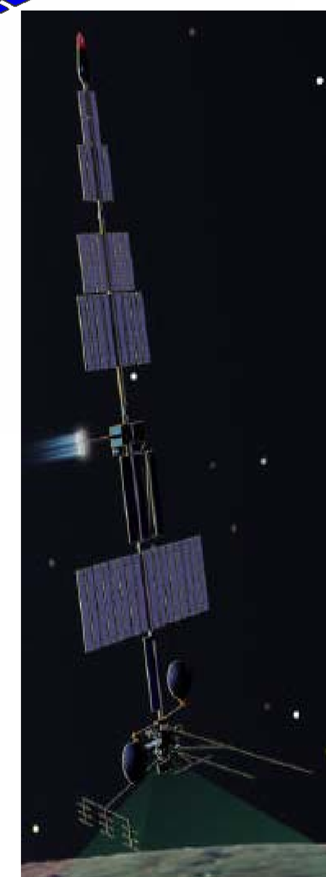
Power Conversion
- Thermoelectric
- Stirling
- Brayton

Heat Rejection
- 2-Phase Loops
- Heat Pipes
- Pumped loops

Technology

- New technologies needed for Prometheus 1:
  - Space Nuclear Power Plant
  - Power Conversion
  - High Power Telecommunications
  - Radiation Hard Electronics
  - Electric Propulsion
  - Low Thrust Trajectory Tools

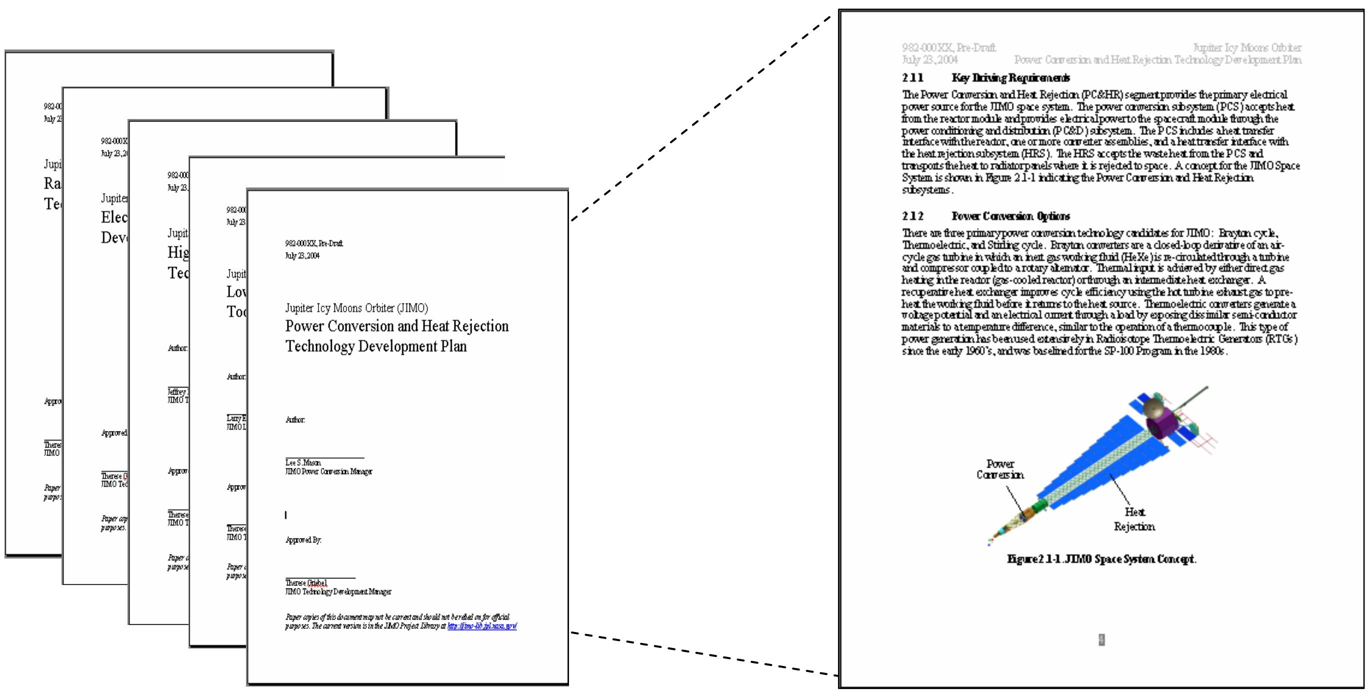




- These technologies must be:
  - Ready on schedule
  - Proven for Prometheus requirements
  - Supportive of future mission requirements
  - Supportive of Safe and Reliable Operations

Technology Development Plans

- Prometheus 1 is managing technologies through detailed "Technology Development Plans"
  - Plans are consistent in establishing success criteria (technology maturity per schedule) which are supportive of JIMO Mission schedule constraints



982-000XX, Pre-Draft
July 23, 2004

Jupiter Icy Moons Orbiter (JIMO)
Power Conversion and Heat Rejection
Technology Development Plan

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982-000XX, Pre-Draft — Jupiter Icy Moons Orbiter
July 23, 2004 — Power Conversion and Heat Rejection Technology Development Plan

2.1.1 Key Driving Requirements

The Power Conversion and Heat Rejection (PC&HR) segment provides the primary electrical power source for the JIMO space system. The power conversion subsystem (PCS) accepts heat from the reactor module and provides electrical power to the spacecraft module through the power conditioning and distribution (PC&D) subsystem. The PCS includes a heat transfer interface with the reactor, one or more converter assemblies, and a heat transfer interface with the heat rejection subsystem (HRS). The HRS accepts the waste heat from the PCS and transports the heat to radiator panels where it is rejected to space. A concept for the JIMO Space System is shown in Figure 2.1-1 indicating the Power Conversion and Heat Rejection subsystems.

2.1.2 Power Conversion Options

There are three primary power conversion technology candidates for JIMO: Brayton cycle, Thermoelectric, and Stirling cycle. Brayton converters are a closed-loop derivative of an air-cycle gas turbine in which an inert gas working fluid (HeXe) is re-circulated through a turbine and compressor coupled to a rotary alternator. Thermal input is achieved by either direct gas heating in the reactor (gas-cooled reactor) or through an intermediate heat exchanger. A recuperative heat exchanger improves cycle efficiency using the hot turbine exhaust gas to pre-heat the working fluid before it returns to the heat source. Thermoelectric converters generate a voltage potential and an electrical current through a load by exposing dissimilar semi-conductor materials to a temperature difference, similar to the operation of a thermocouple. This type of power generation has been used extensively in Radioisotope Thermoelectric Generators (RTGs) since the early 1960's, and was baselined for the SP-100 Program in the 1980s.

Figure 2.1-1. JIMO Space System Concept.

Technology Maturity Criteria

- Structured maturity criteria tables include metrics and success criteria
  - Example: PDR scheduled for 02/08 and technology transfer to NGC begins. All plans account for (1) meeting project schedule dates and (2) readiness for technology transfer

Table 2.2-1. Brayton Technology Maturity Criteria.

Item #	Milestone/ Approx. Date	Test Article Fidelity	Planned Test Conditions	Test Goals	Success Criteria/ Accept. Values
1	2 kW Brayton/Ion Demo (Dec '03)	Sub-scale lab Brayton, NSTAR (EM) thruster	Variable power levels, thruster recycles, thermal-vacuum	End-to-end electrical throughput	Steady-state thruster operations from 0.6 to 1.4 kWe
				AC-to-DC conversion	AC-to-DC efficiency >92%
				Thruster recycle fault tolerance	Repeatable restarts following recycle
2	2 kW Brayton Mechanical Dynamics Test (Sep '04)	Sub-scale lab Brayton, mechanical isolation system, motion sensing instrumentation	Variable power levels, starts/stops, load transients, and speeds, vacuum	Gather induced vibration, torque, and momentum data to validate dynamic analysis code	Experimental uncertainty <20%
3	Advanced Recuperator Core Test (Feb '06)	Representative recuperator core coupons with various geometries and construction materials	Inert gas at scaled flow rates, temperatures, pressures	Demonstrate thermal performance	<2.5 kg/kWt, <2% dP/P
4	Advanced Recuperator (Aug '07)	Subscale lab Brayton (or equivalent) with replacement carbon-carbon-usage recuperator	Design flow rates, temperatures, pressures	Demonstrate advanced recuperator functionality in Brayton power unit	>0.9 Effectiveness, <2.5 kg/kWt, <2% dP/P
				Evaluate mechanical integrity	< 1x10-6 scc/sec stream-to-stream leakage
5	2 kW Brayton Off-Design/Thermal Transient Test (Sept '05)	Sub-scale lab Brayton	Variable power levels, vacuum	Transient and steady state thermal measurements to validate code	Experimental uncertainty <20%
				Demonstrate off-design control methods	Stable operation and mode transition
6	Rotor Support System and Bearing Testing (June '05)	Notional, full-scale rotor with turbine & comp mass simulators, representative journal and thrust bearings	Representative rotor speed and loading	Rotordynamic stability, thermal management, mechanical integrity	TBD N-m startup torque, <5% power loss, <0.1 mm shaft orbit
	(Sept '05 start)	Bearing life specimens	Temperature, environment	Long term durability	Stable torque values, periodic inspections with

Mitigation Options

- Plans include mitigations when success criteria is not met
  - Example: Rad Hard Technology has developed multiple fall-back options depending on timeframe that mitigation become necessary.

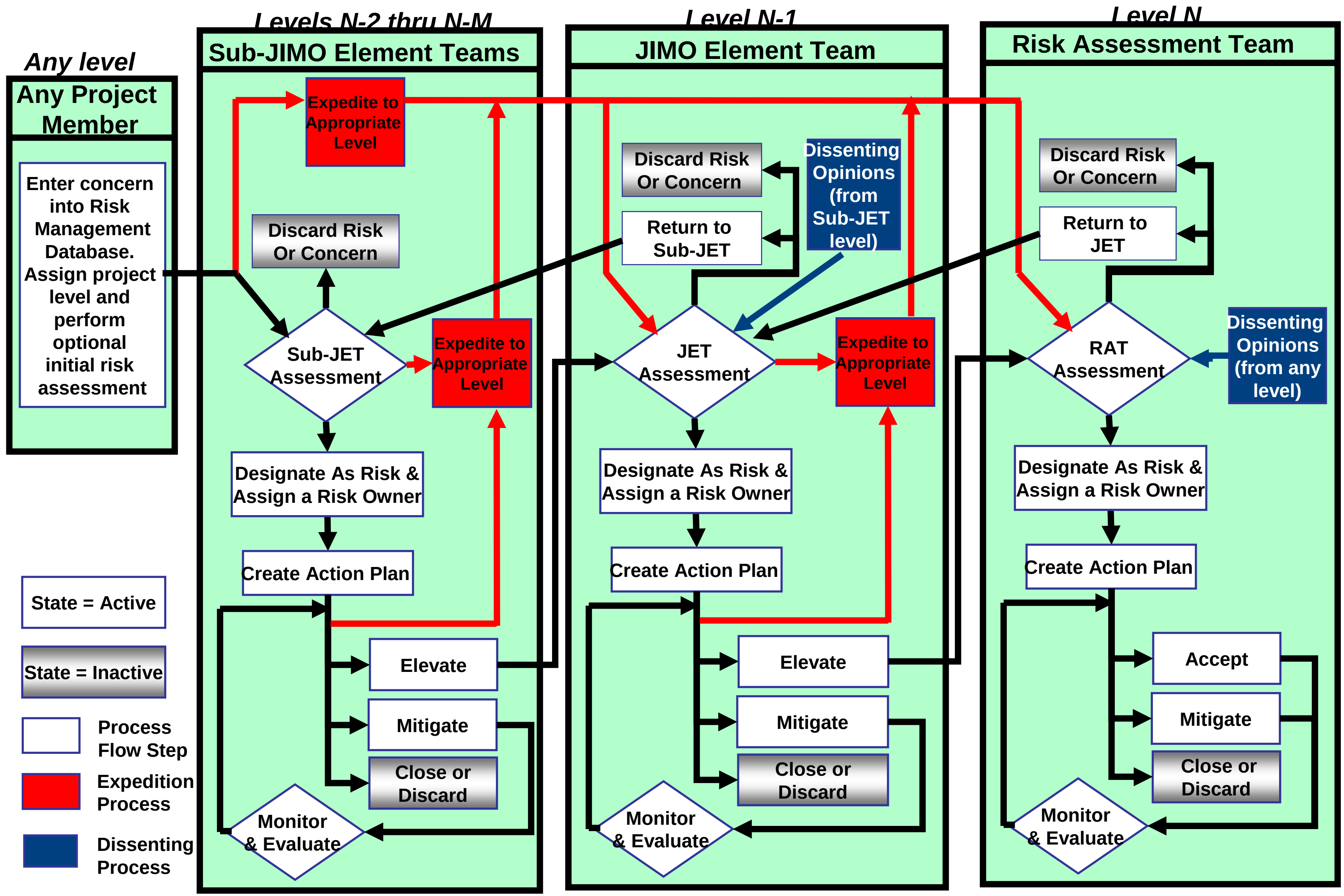
All memory being developed today is clearly driven by the commercial market place and therefore at risk in terms of availability.

Mitigation for product or process non-availability would be three-fold:

- First, the identification of alternate memory technology suitable for use in more than one JIMO RH Memory development. To that end, the JIMO SET recommends the funding of two major technology developments for which a future is certain: 1 Chalcogenide memory funded by AFRL; 2 Ferroelectric technology which has a very wide product and foundry base. For most low speed applications these technologies are interchangeable. Thus if one technology folds, then the other technology could "in theory" be ported over.
- Second, the investigation in the development of ruggedized, radiation tolerant Hard Disk or MEMS drives. This investigation is urged (directed) by the Office of the JPL Director. The SET selected solution for the JIMO Non Volatile Mass Memory subsystem is a complex box containing thousands of memory chips. The technology for the chips cannot be revealed at this time, but what can be said is that, again, should the selector developer run into problems, it is very conceivable that another design house in the same technology could take over. Nevertheless, investigation into completely alternative technologies has begun.

JUPITER ICY MOONS ORBITER
(An element of Project Prometheus)

Risk Management Process



Software Tool and Management Meetings

- Prometheus 1 has chosen Active Risk Manager as the Risk Management Tool
  - All project personnel will have the ability and are responsible to input risks into database
  - All project risks will be tracked in database including Technology

- Regular meetings discuss risks and mitigation plan progress
  - Technology Manager responsible for risk mitigation plan progress at technology detail levels
  - Project Manager chairs Risk Assessment Team meeting to discussing risk mitigation plan progress at the project level
  - Risk Coordination Manager responsible for reporting on risks and their mitigation plans at monthly management reviews
  - Project Manager responsible for reporting on risks and their mitigation plan progress at appropriate JPL and NASA management reviews

Summary

- Risk Management is essential to the development of critical JIMO Mission Technology
- JIMO Technology development is managed through the investment roadmaps and structured success criteria, and will be tracked utilizing the project risk management tool, Active Risk Manager.
- Follow-on mission technology management is underway, supported by the JIMO technology investment roadmaps and the management of the follow-on missions requirements relevant to the Vision for Space