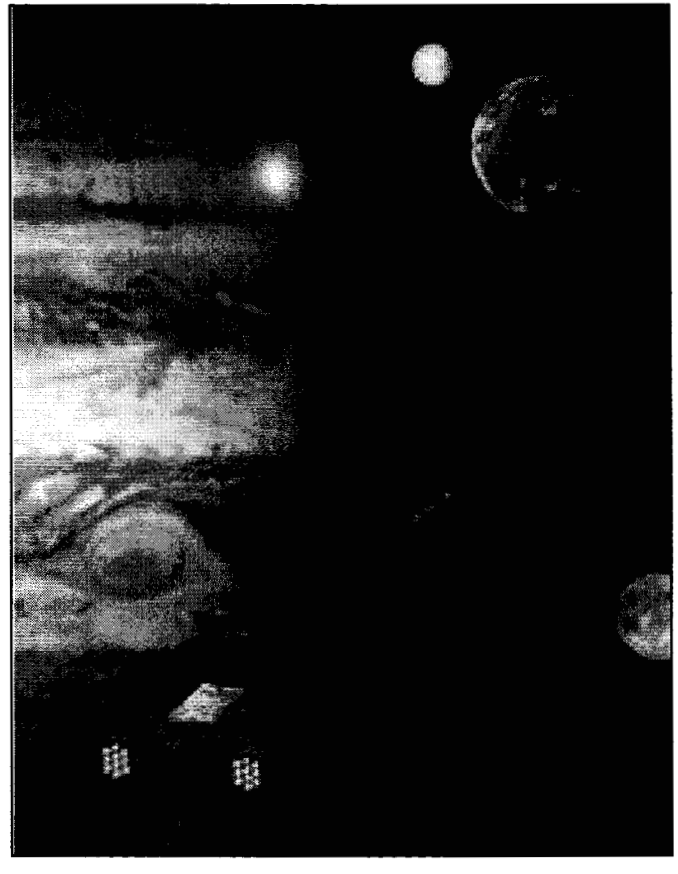
PROJECT PROMETHEUS

Revolutionizing Solar System Exploration

Program Overview



Presented by:

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"...the navigation of interplanetary space depends for its solution on the problem of atomic disintegration..."

Robert H. Goddard, 1907

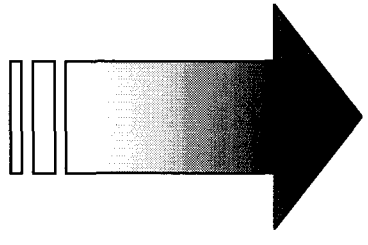
Space Science Enterprise
Agency Vision and Mission

The NASA Vision: "To improve life here, to extend life to there, to find life beyond."

The NASA Mission: "To understand and protect our home planet, to explore the universe and search for life, to inspire the next generation of explorers . . .
as only NASA can."

Space Science Vision

- How did the universe begin and evolve?
- How did we get here?
- Where are we going?
- Are we alone?



Space Science Themes

- Astronomical Search for Origins
- Structure and Evolution of the Universe
- Solar System Exploration
- Mars Exploration
- Sun Earth Connection

The Space Science Vision fully supports the NASA Mission

PROJECT PROMETHEUS
Origin and History

President's FY03 Budget (NASA)

NASA ***Nuclear Systems Initiative*** consisted of:

- **Nuclear Power** (space radioisotope power system development)
  - –Restarts the production of space radioisotope power systems
  - –Develops advanced radioisotope power systems and technologies
  - –First application Mars 2009
- **Nuclear Propulsion** (advanced space technology research and development)
  - –Revolutionizes our ability to explore the solar system
  - –Provides abundant electrical power for propulsion, communication, and science
  - –Enables the maneuverability, adaptability, and capability necessary for in depth exploration
  - –Creates a capability that can be expanded as requirements dictate

No Change

No Change

President's FY04 Budget (NASA)

NASA ***Project Prometheus*** consists of

- **Nuclear Power** (space radioisotope power system development)
  - –No change in overall content
- **Nuclear Propulsion** (advanced space technology research and development)
  - –No change in base technology
- **Jupiter Icy Moons Orbiter** mission
  - –The first application of nuclear propulsion capability
  - –Mission to Europa and other Jupiter moons addresses the highest priority science identified by the NAS Decadal Survey and Aerospace Industry Commission
  - –This mission lays the technological groundwork for ambitious future exploration missions

New

PROJECT PROMETHEUS

Objectives and Benefits

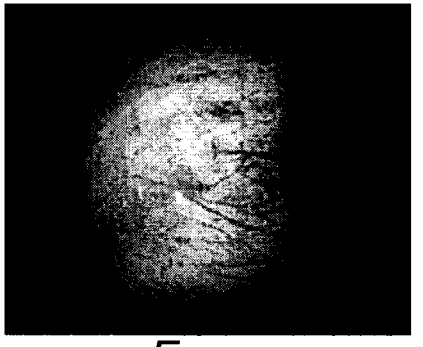
Revolutionize space exploration using space nuclear power and propulsion to enable reaching and studying natural laboratories of the Solar System, and to stimulate future generations of explorers and students.

Direct Benefits

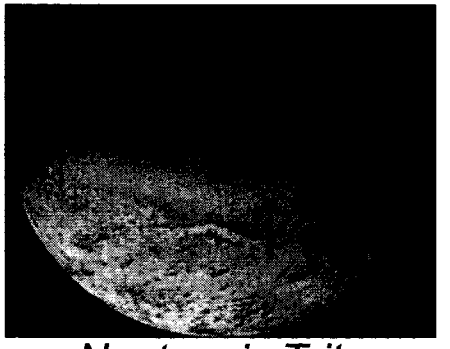
- **Nuclear Power** (radioisotope) enables detailed and extended *in situ* scientific exploration of Solar System locations that cannot be explored in detail using solar or battery power, such as Mars, Europa, Titan, and the Neptune system.
- **Nuclear Propulsion** enables unprecedented exploration of the Solar System, including locations that cannot be reached using chemical propulsion, and lays the foundation for potential future human missions.

Indirect Benefits

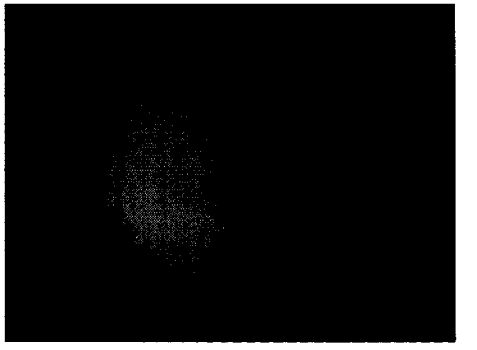
- Compelling stimulus to student interest in technical education from the combination of exciting new space exploration and nuclear propulsion development.
- Terrestrial systems, including next-generation nuclear power, **benefit** from the development of advanced technologies required for space nuclear propulsion.



Europa



Neptune's Triton



Titan

Project Prometheus builds on NASA and DOE's history of safety in the use of nuclear power for space applications

Project Prometheus

Overview

- Safety is the absolute highest priority
- Key components of Project Prometheus
    - Radioisotope power systems development
    - Nuclear propulsion research
    - Jupiter Icy Moons Orbiter (JIMO) development
- Project Prometheus is in addition to the In-Space Propulsion Program already in the baseline

Project Prometheus will enable a new strategic approach to solar system exploration and is likely to play a key role in NASA's future

Match the Power System to the Destination

Main Asteroid Belt | Trojan Asteroids | Centaur Minor Planets | Trans-Neptunian Objects | Kuiper Belt Objects / Comets

Inner Planets

Solar Electric Confined to Inner Solar System
- Also limited reach to large outer planetary bodies with aerocapture (Jupiter, Saturn, Uranus, Neptune only)

Radioisotope Electric for New Frontiers Class Outer Solar System Missions
- –Targets with low Mass
- – 500 W Class RTG
- – <50 kg payload
- –Delta II Launchers

Nuclear Electric for Large Flagship Missions to Outer Planets
- –Large Targets
- –100 kW Class Reactor
- –>500 kg Payloads
- –Delta IV Launch Vehicles

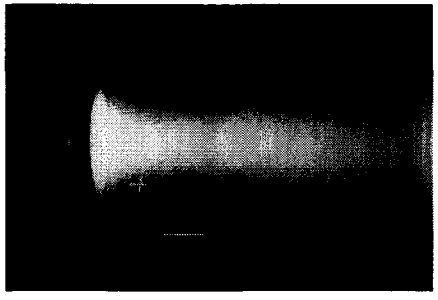
RTG for Surface Lander

Space Propulsion & Power

- Today (chemical propulsion & radioisotope power)
  - Launch, then coast
  - Constricted ability to operate science instruments (power limits)
  - Constricted ability to transmit science data to Earth
  - Constricted launch opportunities (due to gravity assists)
  - Cannot orbit multiple moons of outer planets
    - Limited to fleeting observation from flyby
  - Cannot change target mid-mission

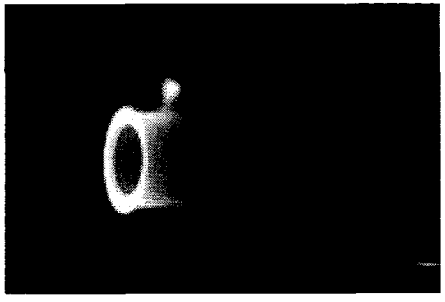
- Future (nuclear electric propulsion)
  - Much greater ability to change speed
  - Much greater (practically unlimited) power for instruments
  - Vastly greater ability to transmit science data to Earth
  - No launch constraint to use gravity assists
  - Can orbit multiple objects or moons
    - Vastly greater, persistent observation time
  - Can change target mid-mission (to support change in priorities)

Electric Propulsion Technologies



Electrostatic Ion

Isp = 2500 - 15,000 sec
Power = 10W - 30kW
Efficiency = 60 – 80%
Mature at 2.3kW
Scales well



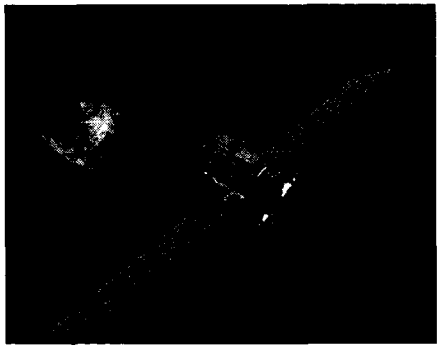
Electrostatic Hall

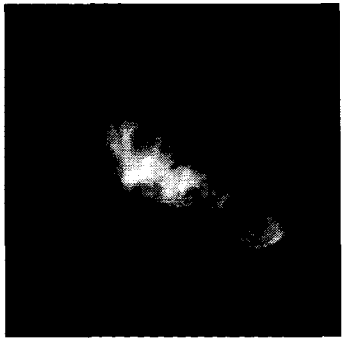
Isp = 1500 - 3500 sec
Power = 100W - 50kW
Efficiency = 45 – 60%
Mature at 1.5kW
Scales well

Electro-magnetic MPD, PIT, VASIMR

Isp = 2000 – 10,000 sec
Power = >100kW
Efficiency = 35 – 50%
Immature
Scaling not understood

Successfully Flew on 1997 Deep Space-1 Mission to Comet Borelly (2.3 kW unit)

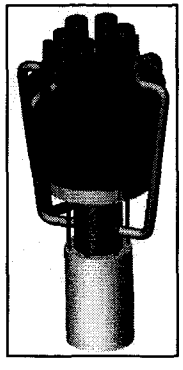




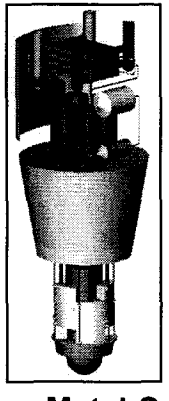
PROJECT PROMETHEUS

Nuclear Electric Propulsion Research Accomplishments to Date

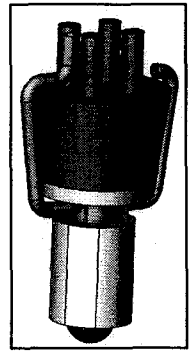
- Fission Reactor
  - Performed detailed nuclear reactor design screening evaluation to formulate acceptable performance parameters for interplanetary science missions
    - Key Participants: DOE HQ, NASA HQ, ORNL, LANL, SNL, GRC, MSFC, JPL
    - Factored in wide spectrum of space reactor operations and planetary science mission considerations
  - Prepared design data packages for reactor concepts showing best potential for safe and successful mission accomplishment
    - Briefed more than 70 individuals from nuclear and aerospace industries and academia on Request for Information (RFI) to support program planning
    - RFI received 10 detailed assessments of reactor technology from industry and academia teams
  - Created electronic archive of legacy space reactor design data at OSTI in Oak Ridge, TN to enable leveraging of past investments by qualified program participants



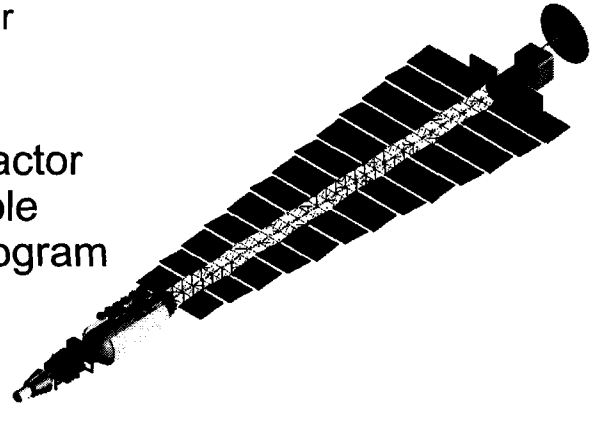
Heat-Pipe Cooled



Lithium Metal Cooled (SP-100 Derived)



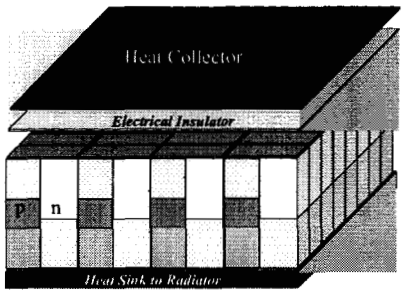
Gas Cooled



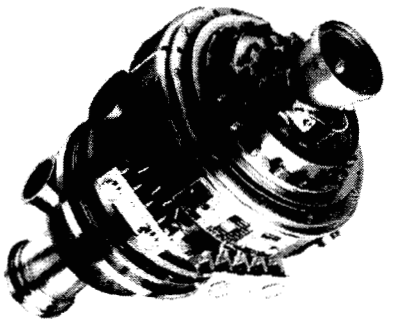
PROJECT PROMETHEUS

Nuclear Electric Propulsion Research
Accomplishments to Date (Cont'd)

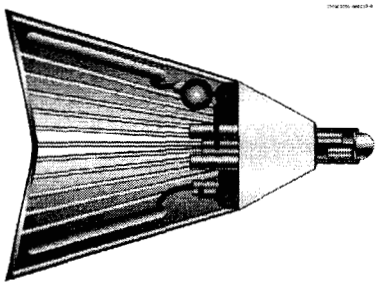
- Power Conversion
  - Awarded Three NRAs
    - Segmented Thermoelectric Multicouple
      - Team led by JPL and includes Boeing, Teledyne, University of Michigan, and University of New Mexico
      - Will advance the technology readiness level and enable high temperature operation up to 1275 K



    - Brayton Power Conversion
      - Team led by Boeing and includes JPL, GRC, Honeywell, Swales, Auburn University, and Texas A&M
      - Will conduct design studies leveraging past space application investments, test key components, and advance technology readiness levels of key components for high power space operations



    - Potassium Rankine Cycle Power Conversion
      - Team led by ORNL and includes Boeing and Swales
      - Will develop stainless steel and refactory alloy designs, optimize cycle performance, and address zero-g two phase flow issues

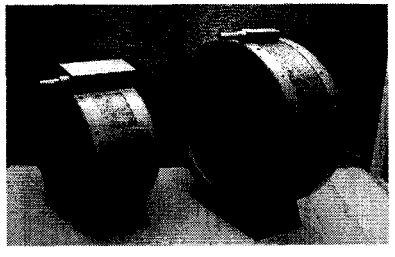


PROJECT PROMETHEUS

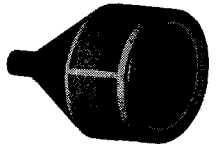
Nuclear Electric Propulsion Research

Accomplishments to Date (Cont'd)

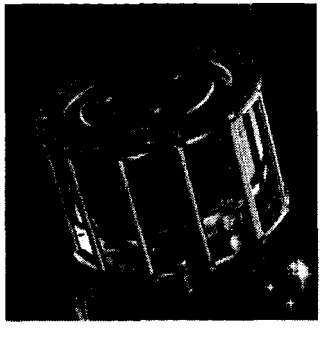
- Electric Propulsion
  - Selected 3 Electric Propulsion NRAs, 2 Awarded
    - High Power Electric Propulsion Ion Engine (Awarded)
      - Team led by GRC and includes Boeing, Aerojet, University of Wisconsin, Univ. of Michigan, Colorado State University, Johns Hopkins/APL, OAI, and NRL
      - Will develop and test high-performance 25 kWe next-generation Ion Propulsion System for deep-space missions, address life issues via microwave propellant ionization and advanced ion optics, and develop simpler, more efficient power processing unit and propellant feed system



    - Nuclear Electric Xenon Ion System (Awarded)
      - Team led by JPL and includes Boeing, Colorado State University, Georgia Institute of Technology, University of Michigan, MSFC, Virginia Polytechnic Institute, and MIT
      - Will demonstrate an ion engine capable of processing 20 kWe at an Isp of 7500 s with an efficiency of 78%, develop component technologies (i.e. carbon-carbon grids) that essentially eliminate the wear-out failure modes, and validate the service life capability through a combination of modeling, testing and in situ diagnostics

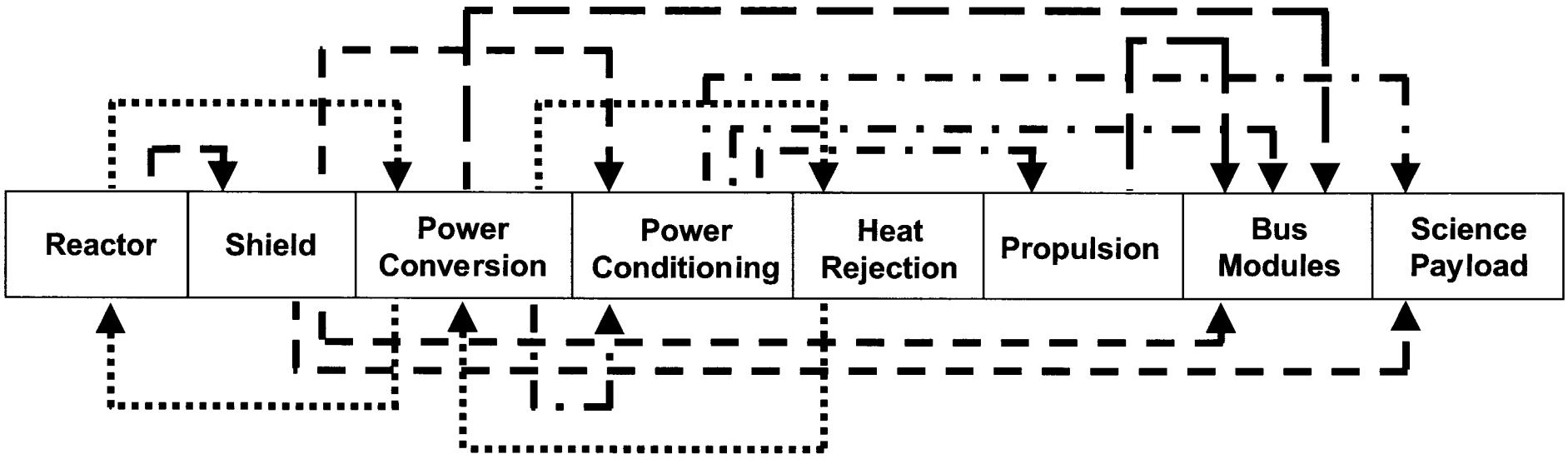


    - Two-Stage Bismuth-Fed Hall Thruster with Anode Layer
      - Team led by Stanford and includes JPL, University of Michigan, Boeing, Lockheed Martin, TsNIIMASH, and Colorado State University
      - Will validate Russian TAL-160 thruster design at 25 kWe (6000 s) and 36 KWe (8000 s), characterize thruster performance in U.S., and assess thruster lifetime and spacecraft contamination potential



Mission Systems Engineering

Interconnection of Subsystems



- Radiation (gamma, neutron; ~ 10^14 / cm2 sec)
- Thermal / Working Fluid Loops (~ 0.4 – 1.4 MWth)
- Electrical Power (~ 0.1 – 0.35 MWe)
- Angular Momentum / Torque (if Brayton)

Numerous feed forward and feedback links between major subsystems. Necessitates highly integrated missions systems engineering in the context of deep space operations, including in orbit around planets and moons.

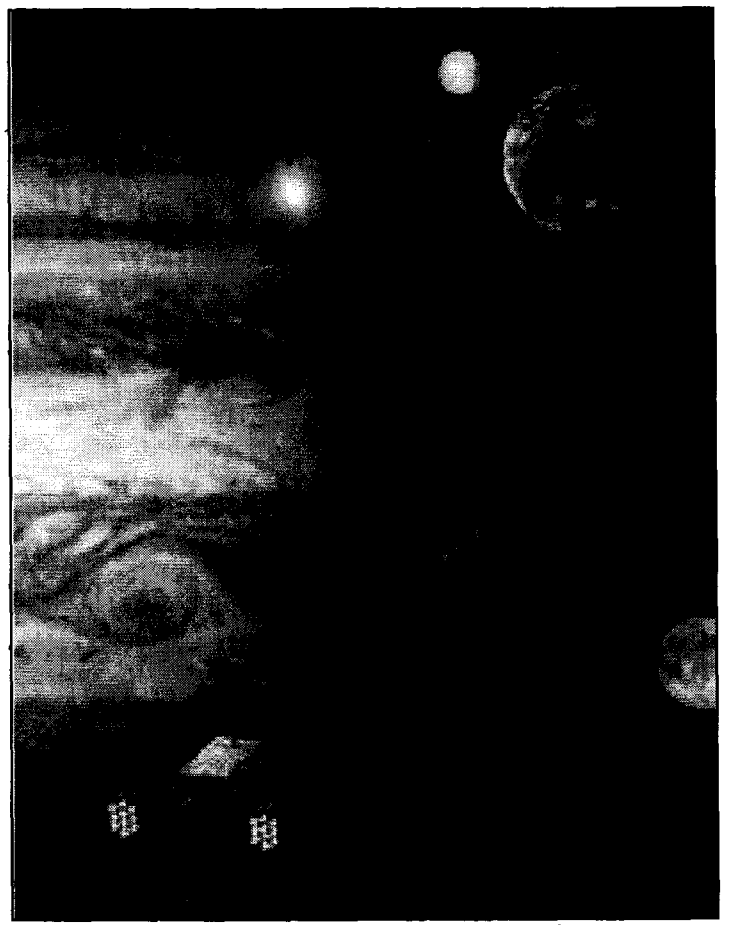
NASA's Space Science Strategic Plan Enabled by Nuclear Electric Propulsion

Example of Space Science NEP candidate missions

- **Revolutionary Exploration Missions (multiple destinations per Mission) to meet NASA's most challenging exploration goals**
  - JIMO (orbital characterization of Europa, Ganymede, Callisto)
    - Europa is # 1 Large Mission in NRC's Decadal Survey
  - Titan Orbiter and Surface/Atmosphere Explorer
  - Neptune System Orbiter & Kuiper Belt Object Reconnaissance
    - Kuiper Belt Objects are #1 Moderate Mission NRC's Decadal Survey
  - Comet Chaser
- **Revolutionary Missions and Capabilities Using Surface Nuclear Power**
  - Lunar and Mars Surface Power for Science, Human Exploration, Deep Subsurface
- **Earth Protection Support**
  - Multiple Near-Earth Object (NEO) Reconnaissance and Characterization (the NEO "prospector" mission) and potential mitigation

Project Prometheus:
Jupiter Icy Moons Orbiter (JIMO)

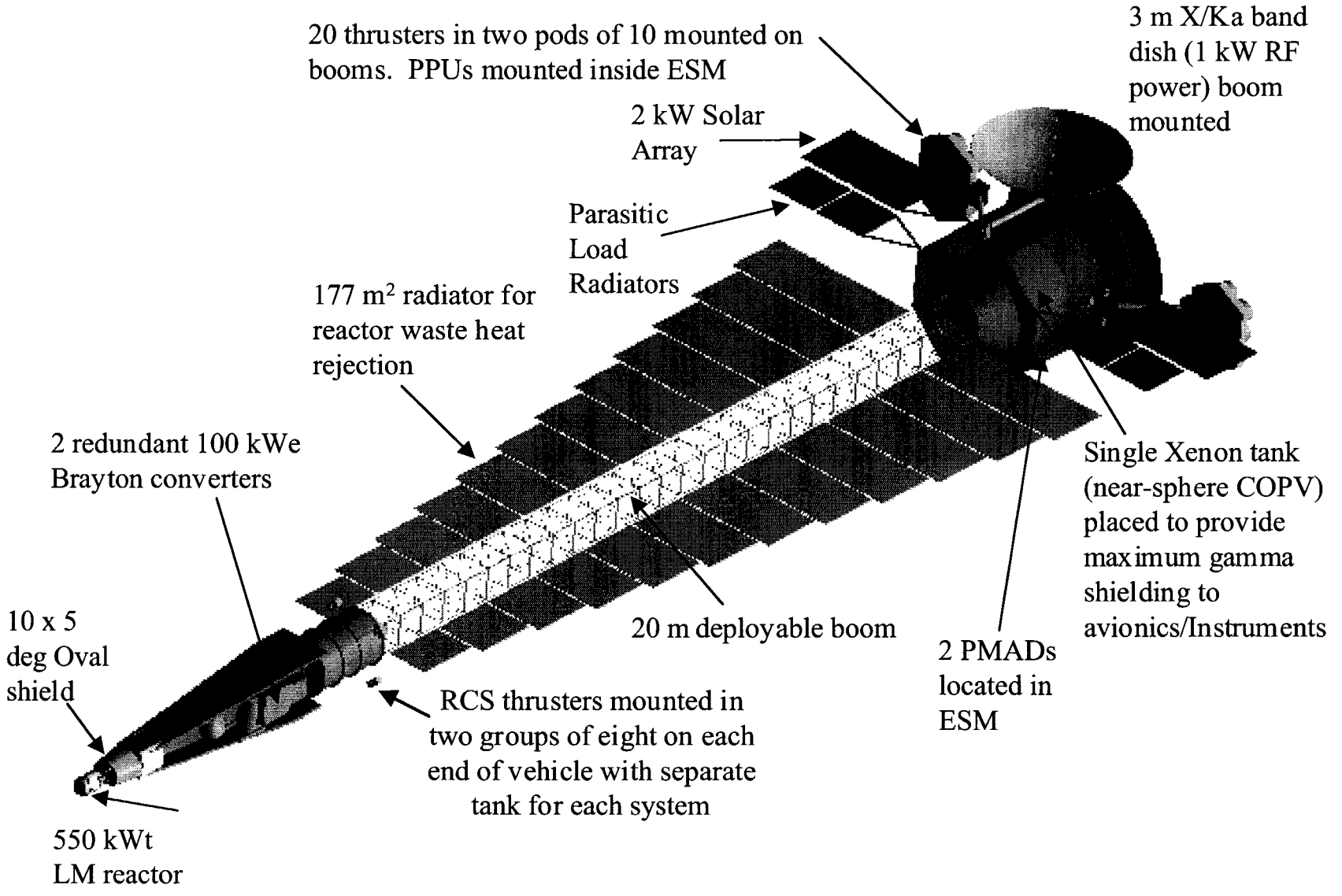
- This mission responds to the National Academy of Sciences' recommendation that a Europa orbiter mission be the number one priority for a flagship mission in Solar System exploration.
- JIMO will search for evidence of global subsurface oceans on Jupiter's three icy moons: Europa, Ganymede, and Callisto.
- JIMO will be the first flight mission to use nuclear power and propulsion technologies.



Artist's concept

- 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.

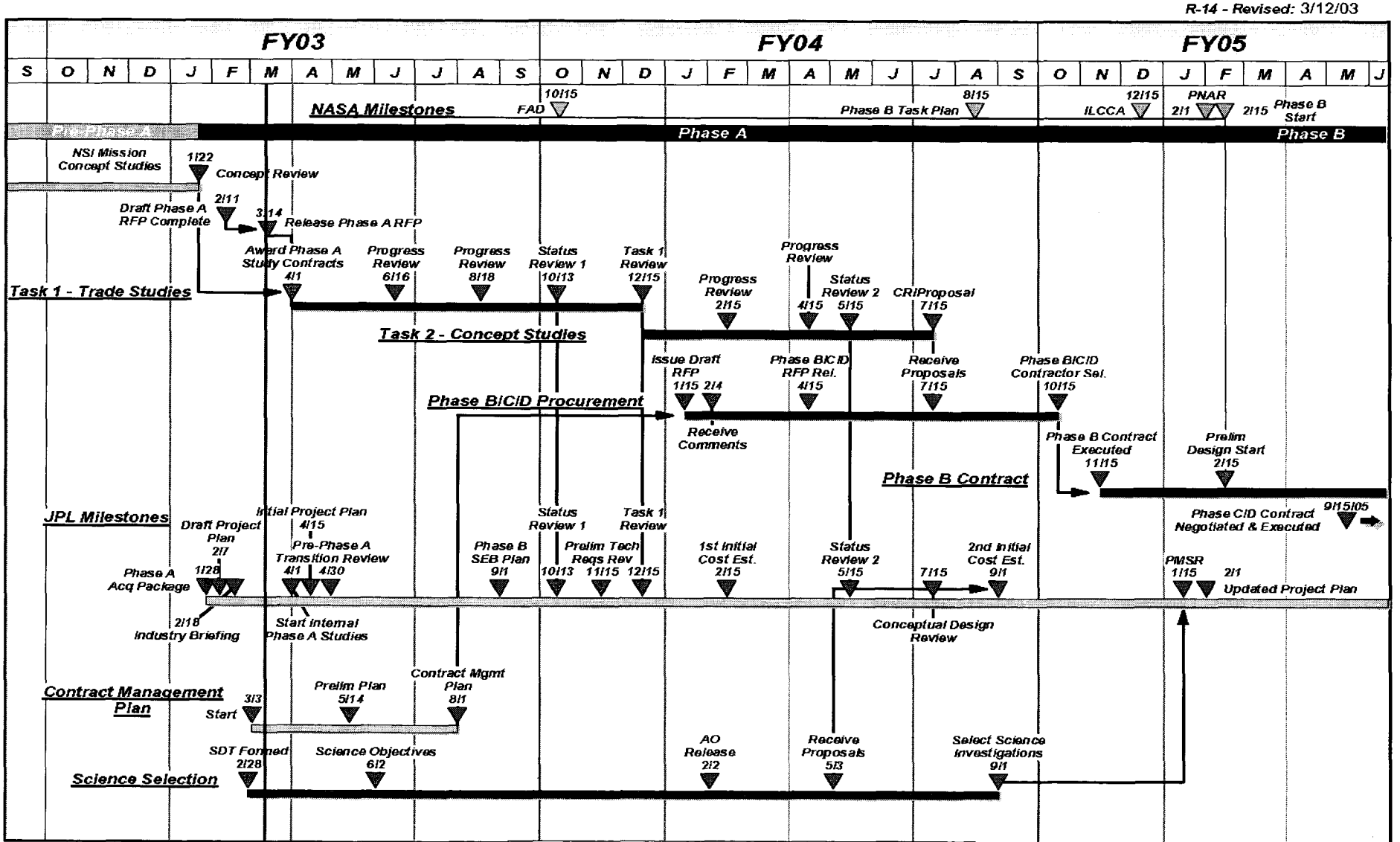
Baseline Configuration



PROJECT PROMETHEUS

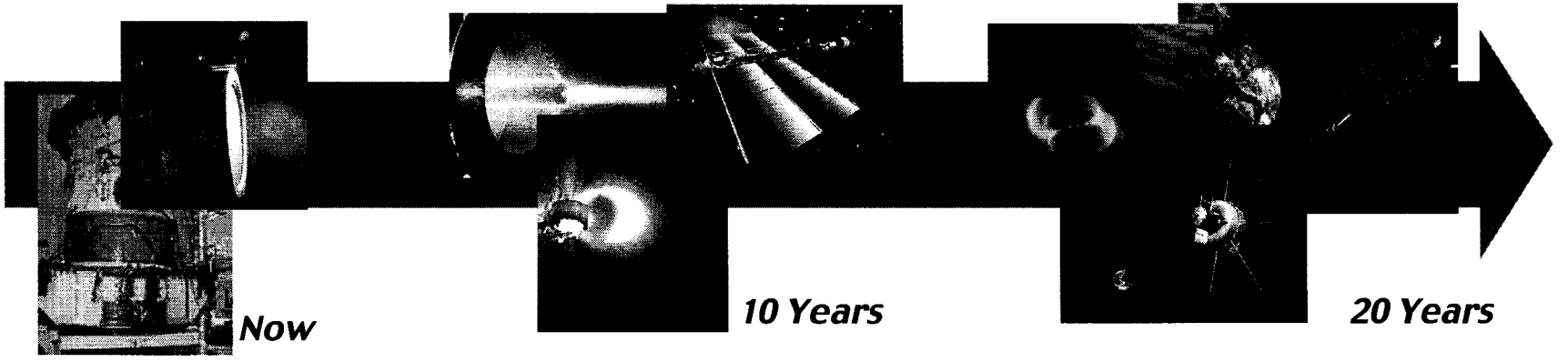
JIMO Near Term Schedule

R-14 - Revised: 3/12/03



Pre-Decisional For Internal Discussion Purposes Only

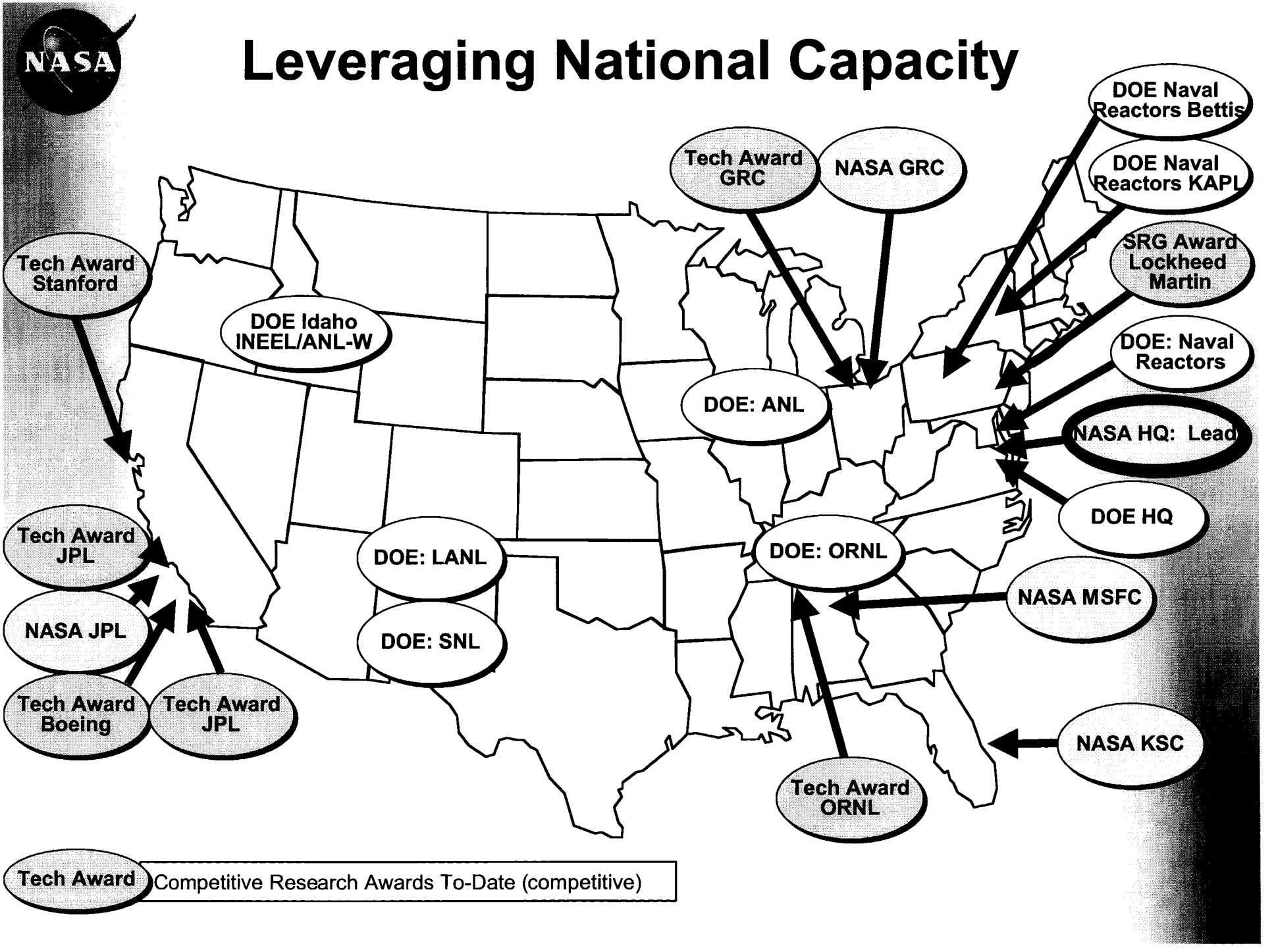
Many Technologies Extend to a Broad Range of Future Space Exploration Missions



- **Many of the technology, fabrication, and ground-based capacities developed for the first space nuclear propulsion mission have direct application to follow-on missions**
  - Nuclear fuel and clad & fabrication capacity
  - Nuclear reactor design, analysis, and qualification methodology and software
  - Neutron and gamma shield, and neutron reflector & fabrication capacity
  - Radiation-tolerant nuclear reactor instrumentation and control & fabrication capacity
  - Space nuclear reactor power system autonomy
  - Power conversion & fabrication capacity
  - Low mass, large-scale radiation-tolerant thermal radiators & fabrication capacity
  - High power density electrical power control and distribution & fabrication capacity
  - High power electric propulsion & fabrication capacity
  - Safety and launch approval procedures, National Environmental Policy Act procedures and actions
  - Ground test facility and support equipment (both for zero-power critical testing, and potential full power testing)

Evolvable technologies for follow-on science driven exploration missions

Leveraging National Capacity



Summary

- **Safety is the absolute highest priority**
- **Project Prometheus Program will revolutionize the scientific exploration of the Solar System**
- **Awarded six NRA's for nuclear propulsion research**
- **The proposed JIMO mission will start a new generation of missions characterized by more maneuverability, flexibility, power and lifetime**
- **Completed preliminary studies (Pre-Phase A) of JIMO and other missions**
- **Three JIMO trade study contracts have been awarded**
- **NASA and DOE are beginning to leverage national capacity to carry out this ambitious program**

"...I wouldn't be a bit surprised if we flew to Mars electrically."
Werner von Braun, 1947