To Europa and Beyond (Enabled by a Small RPS)

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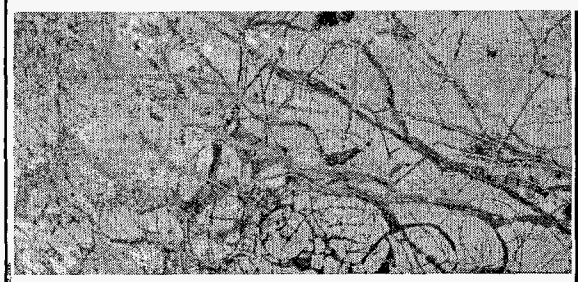
Outline

- Study assumptions and ESSP concept mission scenario
- ESSP science requirements and instrument options
- Study drivers (e.g., mass limit, radiation, landing method, small-RPS concept)
- Parametric results and point concepts
- Conclusions
- Beyond Europa with Small-RPSs (& RPSs, ARPSs & fission)

Study Assumptions



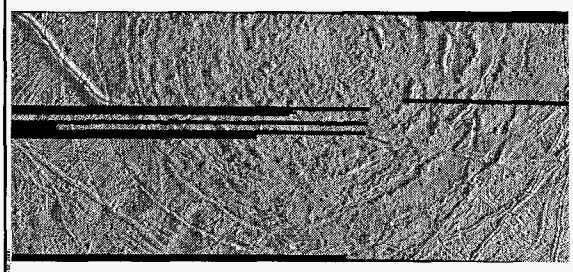
Study Assumptions

- Technology cutoff by 2012 (assumptions will support feasible trades and not far-out technologies)
- The ESSP is deployed from an assumed JIMO orbit
- As assumed in this study, JIMO would provide 1" of aluminum shielding until ESSP deployment (a simplification for this study) (the high radiation environment may necessitate this type of help from JIMO)
- Radiation hardened components on ESSP up to 1MRad tolerance
- Dual string design
- Advanced technology for all components
- 30% contingency on mass and power (required by design principles for concept studies)
- Some instrument operation cycled to reduce power requirements
- Cost, Planetary Protection & Surface Contamination issues were not addressed for this trade space exploration

Conceptual ESSP Mission Scenario

- ESSP would cruise to Europa inside or attached to JIMO
- JIMO would orbit Europa on a 100 km orbit with an inclination of 110°
- During it's 30-day science floor first JIMO would map Europa, from which a landing location would be determined
- The Europa Surface Science Package would deploy for a 3 / 7 / 14 (Earth-)day Europa surface mission
- Data would be communicated from ESSP to JIMO during overpasses utilizing JIMO's telecom system
- JIMO would downlink the ESSP data to DSN

ESSP Science Requirements and Instrument Options



Science Goals Expressed by the JIMO SDT

- **Astrobiology**
  (Search for organic materials, determine composition; chemical patterns, organics indicative of biological origin)
- **Geophysics**
  (Acoustic/seismic; icy crust thickness; ocean depth; geophysical and mechanical ice properties; magnetic field at surface, surface package tracking for geodynamics)
- **Geological-compositional**
  (provide "ground truth"; elemental composition; mineralogical characterization; physical properties & high-resolution morphology & density & thermal / electromagnetic properties & surface processes & radiolysis of surface materials)

Reference:
Greeley, R., Johnson, T., "Report of the NASA Science Definition Team for the Jupiter Icy Moons Orbiter (JIMO)", NASA Report, February 13, 2004

Additional information on this study can be found in the ESSP feasibility study report, JPL D-30050, released in September 2004

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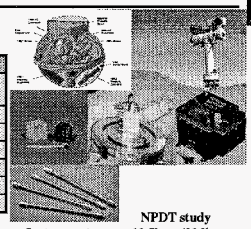
Two Representative ESSP Instrument Set Examples

Team-X study
Instrument mass ~10kg with 30% contingency

Instrument	Power	Comment
Gas Chromatograph / Mass Spectrometer (GC/MS)	8 W for GC 2 W for MS	GC – 1 measurement; MS – several samples
Micro-Seismometer	0.25 W	Non-stop operation
Magnetometer	0.5 W	Non-stop operation
Imager (x)	2 W	10 minutes / 24 images
Radiation detector	< 0.25 W	Periodic operation
Raman Spectrometer	N/A	Not included
Wet chemistry	N/A	Not included



- Based on NPDT design session discussions with JIMO SDT members, the "GC/MS & no Wet Chemistry" from the Team-X study was replaced with an **Organic Detector plus a Mini Mass Spectrometer**, supporting the same science objectives as GC/MS + Wet Chemistry
- **Issues:** (examples only) Seismometer sensitivity; radiation impact on imager; GC/MS+Wet Chemistry vs. OD+Mini MS

The two strawman instrument sets were picked to demonstrate that the JIMO SDT set science goals could be achieved with a variety of instrument options. A potential future point design should select instruments concurred by the JIMO SDT.

NPDT study
Instrument mass ~12.5kg w/30%
Meets science goals of JIMO SDT

Instrument	Power	Comment
Organic Detector	10 W	1 hour (NEW)
Mini Mass Spectrometer	1.0 W	1 hour (NEW)
Seismometer	2.7 W	Continuous (NEW)
Radiation detector	0.3 W	Continuous
Magnetometer	0.5 W	Continuous
Panoramic Camera	4.3 W	~15 minutes

Additional information on this study can be found in the ESSP feasibility study report, JPL D-30050, released in September 2004

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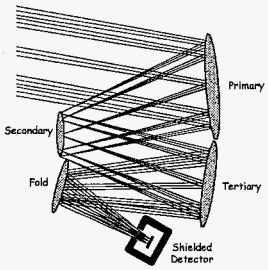
Use of Reflective Optics in High-Radiation Environments

Three-Mirror Anastigmat with Fold (Raytrace)

Operating in Extreme Environments such as on Europa requires **special considerations for instrument design and operations** as show through this example

- **All-reflective optical systems** represent an optimal solution in high-radiation environments
- Has been **proposed for** use in planetary missions in which the instruments will be subjected to high radiation doses, such as **Io, Europa** and **Ganymede**.
- Absence of **refractive** elements which **can darken**, suffer refractive index changes or even **deform** due to changes in the glass / crystal structure after exposure to radiation.
- **All-reflective** optics are inherently achromatic, that is, have the **same optical performance over a wide spectral bandwidth**.



Breaking information: CMOS imaging (currently at TRL 4-6) could provide significant advantage over CCD's on Europa in image quality, radiation and temperature tolerance and lower power requirements (~100mW only)!

Additional information on this study can be found in the ESSP feasibility study report, JPL D-30050, released in September 2004

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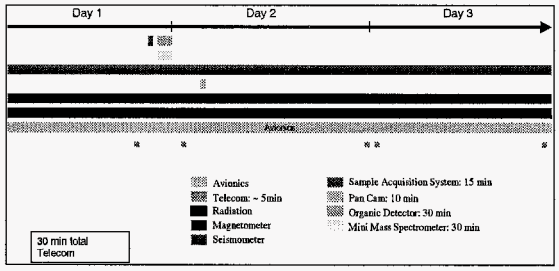
Mission Scenario Example for 3 Days of Surface Operation



Power system scaling required:
- an established list of instruments and subsystems,
- which list then was used to define mission scenarios
- for 3, 7 and 14-days of surface operation
- assuming a secondary battery + small-RPSs

Additional information on this study can be found in the ESSP feasibility study report, JPL D-30050, released in September 2004

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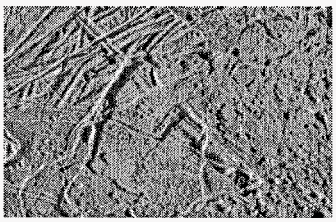
Study Drivers



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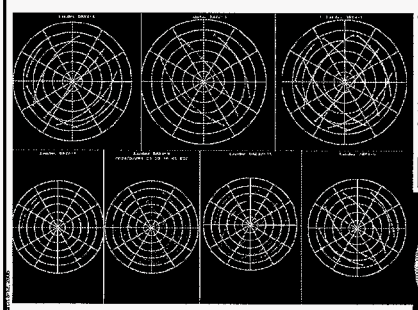
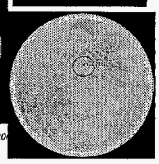
Trajectory/Telecom Example Based on the Assumed JIMO Orbit

14 Days of Overhead Passes by JIMO



Telecom availability:
- 3 days → 30 minutes
- 7 days → 60 minutes
- 14 days → 120 minutes

2 day increments / chart
Time tick: 1 minutes



Software: SOAP (Satellite Orbit Analysis Program) v.11.80, The Aerospace Corporation, 1989-20

Additional information on this study can be found in the ESSP feasibility study report, JPL D-30050, released in September 2004

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What makes the ESSP mission so challenging?

Key Study Drivers	Comment
Initial mass constrained	ESSP mass is limited to up to 25% of JIMO's payload (375kg). Note: this is the lowest allocated mass among previously studied landing configurations, listed earlier.
Radiation environment	Without shielding the ESSP (& JIMO) would be exposed up to ~60 MRad of Total Ionizing Radiation (TID). Shielding, to reduce radiation exposure, may significantly impact the mass.
Rocket equation $\Delta V = g_0 I_{sp} \ln \frac{m_{initial}}{m_{final}}$ $m_{final} = m_{initial} - m_{propellant}$	**ΔV** to land ESSP is set, and it is the function of the JIMO orbit. Landing even the smallest payload requires a significant amount of mass for propellant, propulsion dry mass, and structures. This sets a required limit on the mass and bounds the ESSP payload mass when the initial mass is constrained.

Additional information on this study can be found in the ESSP feasibility study report, JPL D-30050, released in September 2004

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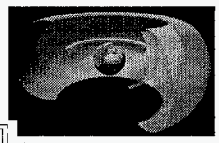
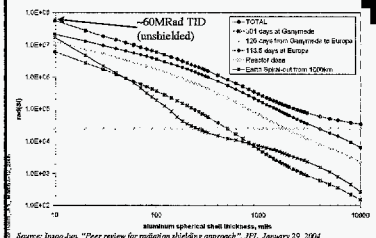
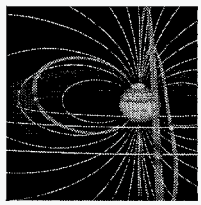
Study Drivers – Radiation Related Issues

- Radiation sources throughout the proposed JIMO mission:
  - Van Allen Radiation Belts
  - Galactic Radiation
  - Jupiter's Radiation Environment
  - JIMO's Fission Reactor
  - (Small-RPSs on the ESSP)







Source: Insoo Jun, "Peer review for radiation shielding approach", JPL, January 29, 2004

Additional information on this study can be found in the ESSP feasibility study report, JPL D-30050, released in September 2004

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Study Drivers – Radiation Environment

Total Ionizing Dose (TID) Radiation during JIMO tour

Shielding	No shielding	100 mil (2.54mm)	1000mil (25.4mm)
TID (RDF=1)	~60MRad	~6MRad	~0.3MRad

Source: Insoo Jun, "Peer review for radiation shielding approach", JPL, January 29, 2004

TID for ESSP Shield Sizing (in MRad)

Number of days on Europa	1000 mil (1") on JIMO plus 100 mil on ESSP		1000 mil (1") on JIMO plus 5 mm on ESSP		1000 mil (1") on JIMO plus 10 mm on ESSP	
	RDF=1	RDF=2	RDF=1	RDF=2	RDF=1	RDF=2
14	0.72	1.43	0.63	1.25	0.40	0.80
7	0.51	1.02	0.44	0.89	0.33	0.66
3	0.40	0.79	0.36	0.73	0.32	0.63

Scaling calculations by T. Balint, JPL

- The TID includes the radiation level that ESSP is exposed to during JIMO cruise + on Europa's surface
- All electronics components are assumed to tolerate up to 1MRad
- RDF – Radiation Design Factor is similar to a safety factor; typical value is 2
- The TID values do not include radiation from Radioisotope Power Systems.
  3 General Purpose Heat Source (GPHS) modules would add ~0.09MRad to the above values.

Additional information on this study can be found in the ESSP feasibility study report, JPL D-30050, released in September 2004

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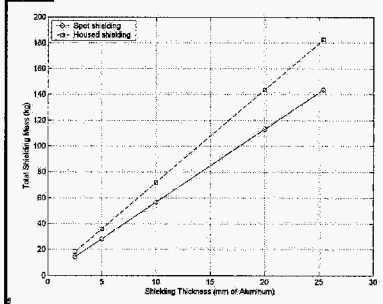
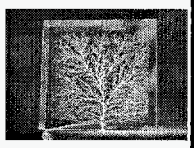
Study Drivers – Shielding Mass Estimates for an ESSP Concept





Note that beside radiation shielding other aspects of radiation exposure (such as material charging) should be accounted for in the final point design.

Detailed design for the ESSP should properly account for shielding, including optimization!

Additional information on this study can be found in the ESSP feasibility study report, JPL D-30050, released in September 2004

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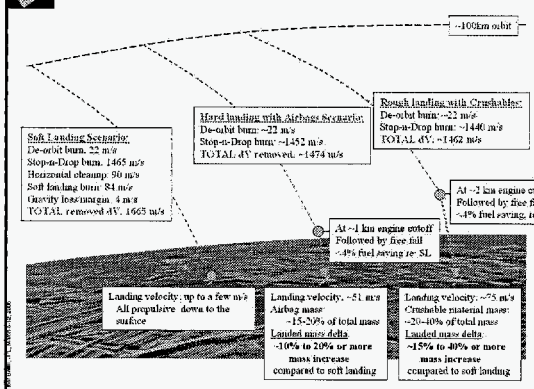
Study Drivers – Comparison of Landing Methods (as a function of Landed Mass)



Additional information on this study can be found in the ESSP feasibility study report, JPL D-30050, released in September 2004

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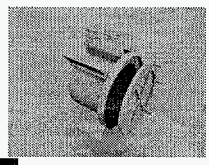
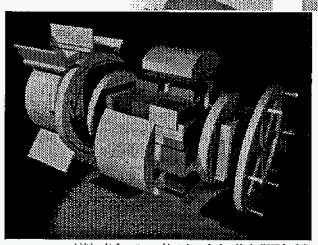
Study Drivers – Small-RPS Concept – based on 1 GPHS module





- Small-RPSs are under consideration by the US DoE and by NASA
- Notice of Intent (NOI) to develop them was issued in September 2004
- Request for Proposals (RFP) from the DoE is expected in early 2005
- Could be made available as early as the 2011 Mars Scout launch opportunity

Additional information on this study can be found in the ESSP feasibility study report, JPL D-30050, released in September 2004

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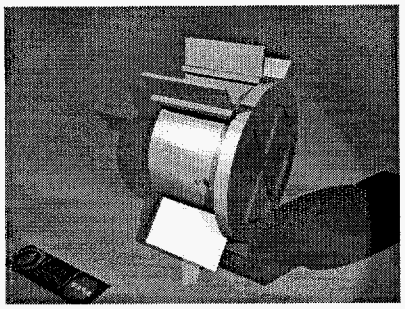
Study Drivers - Anatomy of a Small-RPS Concept



Note: This small-RPS concept was inspired by the works of R. Wiley (DoE) and R. Carpenter (OSC)

Additional information on this study can be found in the ESSP feasibility study report, JPL D-30050, released in September 2004

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Parametric Results & Point Concepts

Additional information on this study can be found in the ESSP feasibility study report, JPL D-30050, released in September 2004

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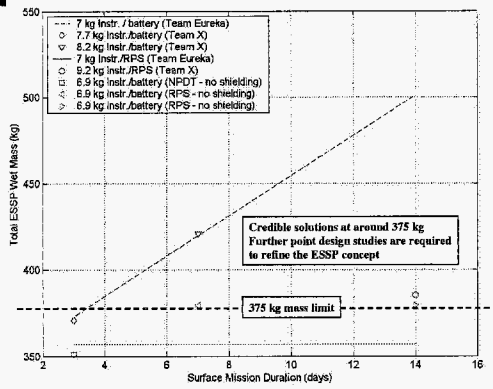
Comparison of Parametric, Team X and NPDT Study Results



Additional information on this study can be found in the ESSP feasibility study report, JPL D-30050, released in September 2004

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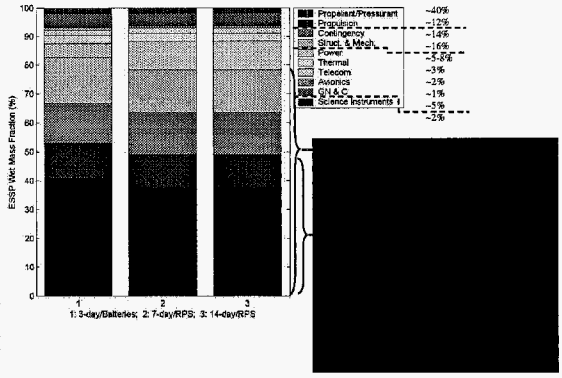
Mass Fraction Breakdown of ESSP Concept (by NPTD)



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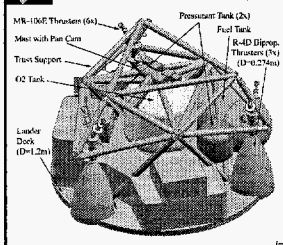
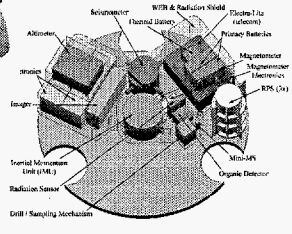
ESSP Concept: Soft Landing & Small-RPSs



NOTE: Point concepts shown here do not represent a final point design! These were only used to gain confidence in the parametric scaling results and to test preliminary ideas and concepts.



An **RPS enabled** lander require smaller (secondary) batteries

Waste heat could be utilized to keep the WEB (Warm Electronics Box) above survival temperature

Additional information on this study can be found in the ESSP feasibility study report, JPL D-30050, released in September 2004

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Conclusions on the ESSP Study

- ✓ Key drivers for Europa Surface Science Package:
  - ✓ Limited initial mass (up to 375 kg, that is 25% of the proposed JIMO mission's current payload)
  - ✓ High radiation environment adds significant shielding mass (the shielding alone accounts for ~20-180 kg!!; worst case is without shielding help on JIMO)
  - ✓ Rocket equation: Propulsion alone is ~50% of the total mass
  - ✓ Constraints: (a) set initial mass; (b) technology sizes the landed asset mass (we assumed advanced technologies); (c) radiation sizes shielding mass
- ✓ With realistic assumptions for a 2012 technology cutoff date
  - ✓ ESSP mass allocation seems **possible within the 375 kg limit**;
  - ✓ 300 kg and 150 kg initial masses are likely not feasible.
  - ✓ **Soft landing** delivers the **highest payload** compared to hard and rough landing configurations;
  - ✓ Airbag and Crushable rough landings are less mass efficient on planetary bodies without atmospheres, thus such designs will exceed landed mass limit. It is more efficient to remove all delta V with one type of propulsion system / landing method!
  - ✓ **For short duration, that is 3 days** (maybe 7), **batteries** provide a good power source option (mass efficiency cross over between battery & RPS based landers is ~5 days);
  - ✓ For a 7 **to 14-day mission small-RPSs could be considered;**

Additional information on this study can be found in the ESSP feasibility study report, JPL D-30050, released in September 2004

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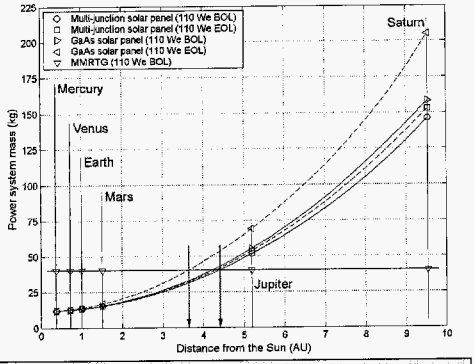
Beyond Europa: Comparison of Solar and RPS Power Generation



Beyond ~4AU RPS power generation is more mass efficient than solar power generation…

Additional information on this study can be found in the ESSP feasibility study report, JPL D-30050, released in September 2004

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Beyond Europa: Mission Concepts – Enabled by Small-RPSs and above

- Milliwatt range (10s to 100s of mW_e)
  - Micro landers, rovers and impactors
  - Deployable science micro instruments, such as seismic stations, beacons
  - Targeting asteroids, moons (Moon, Europa, Titan), Mars, planetary rings
- Multiwatt power range (10s of W_e)
  - Landers and rovers to Europa, Titan, Ganymede, Callisto, the Moon, Mars
  - Venus aerobot
  - Communication relay satellite / Orbiter satellites
  - Sub-satellites and adjunct payloads on flagship class missions
- Multi-hundred watt range (100 W_e to ~1 kW_e) with RPSs and ARPSs
- Tens of kW_e to hundreds of kW_e and above with fission reactors
- *Note, a more complete list of small-RPS and standard RPS enabled mission concepts is given in:*
  - Abelson, R.D., Balint, T.S., Marshall, K.E., Noravian, H., Randolph, J.E., Satter, C.M., Schmidt, G.R. and Shirley, J.H., 2004. "Enabling Exploration with Small Radioisotope Power Systems", Technical Report JPL Pub 04-10, NASA, Washington, D.C., September: and

  - Abelson, R.D., Balint, T.S., Coste, K., Elliott, J.O., Randolph, J.E., Schmidt, G.R., Schriener, T., Shirley, J.H., Spilker, T.R., 2005. "Expanding Frontiers with Standard Radioisotope Power Systems", Technical Report JPL D-28902, PP-266 0332, NASA ,Washington, D.C., January

Additional information on this study can be found in the ESSP feasibility study report, JPL D-30050, released in September 2004

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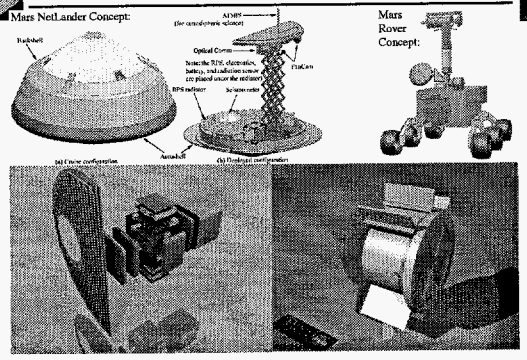
Beyond Europa: Small-RPS Enabled Mission Concept Examples



Small-RPSs could also be used on missions within 4AU (e.g., on Mars), where solar insolation is not available and long mission duration is required

Additional information on this study can be found in the ESSP feasibility study report, JPL D-30050, released in September 2004

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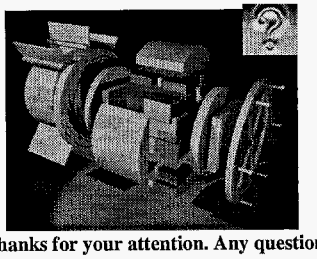
Special thanks to the JIMO SDT, to Curt Niebur, and to all contributing members of JPL's Team-X, NPDT and MBED teams



Thanks for your attention. Any questions?

(Further information on this topic can be found in the ESSP report)

Additional information on this study can be found in the ESSP feasibility study report, JPL D-30050, released in September 2004

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