A.4.4 ADVANCED ELECTRIC PROPULSION (AEP) TECHNOLOGIES

1. Scope of Program

In support of Project Prometheus, the Nuclear Systems Program, the NASA Office of Space Science (OSS) solicits research and development in the area of advanced electric propulsion (EP) thruster technologies, other than gridded ion or Hall, that have the potential to enable very high thruster power (100 to 250 kW electric (kWe) per thruster). The goal of this AEP Technologies program is not to develop flight-qualified hardware, but to promote and advance the development of very high power, AEP thruster technologies that result in reduced AEP system mass and complexity and that may enable future missions that might otherwise not be considered credible and to deliver conceptual AEP system designs. As spacecraft power levels become very high, building high powered gridded ion or Hall thrusters (>100 kWe) or clustering large numbers of moderately powered (~25 kWe) thrusters becomes massive, voluminous, and complicated. The proposed AEP thruster system must offer advantages at a system level over an equivalently performing gridded ion or Hall thruster systems, as well as improvements in component and system lifetimes and performance over the current state-of-the-art (SOA) of AEP systems. Although this NRA is focused on 100 to 250 kWe applications, this AEP technology is expected to be evolvable to the larger power levels needed for several hundred kilowatt to megawatt AEP applications. As a reference point for assessing desired mass improvements over SOA gridded ion and Hall thruster systems, mass parameters for a representative Nuclear Electric Propulsion (NEP) ion system are presented in Table 1 below for a hypothetical 500 kWe deep space application. Also, representative EP system information for various types of EP systems at 20 kWe and above, including references, is provided in Table 2 below.

This NRA solicits research and development activities that lead to a demonstration of a breadboard EP thruster system in a laboratory or relevant environment that meet or exceed the following performance goals:

- Individual thruster power levels between 100 and 250 kWe with total power provided to the EP system of up to 500 kWe.
- Electric propulsion system alphas (kg/kWe) less than two to four (EP propellant tankage and propellant are not to be included in the alpha calculation).
- Specific impulse from 4,000 to ≥ 10,000 seconds.
- Thruster efficiencies equal to or greater than 60%.
- EP system lifetimes of one to three years.

A major objective of this NRA is to conduct studies to be completed within six months of award (base period of performance), potentially leading to a full-scale laboratory demonstration of an AEP thruster system within three years that satisfies all of the aforementioned performance goals. The proposed EP thruster technology must be demonstrated and validated at a Technology Readiness Level (TRL) of 3 or above for the proposal to be considered. (For definitions of TRL, see Appendix E.11 of the OSS Management Handbook at http://spacescience.nasa.gov/admin/pubs/handbook/OSSHandbook.pdf.)

Table 1. Representative Very High Power NEP Ion System for Hypothetical Deep Space Application

Spacecraft Mass Definition	
Power	500 kW
Power System Alpha	20 kg/kW
Power System Mass	10,000 kg
Ion Propulsion System Total Specific Mass	4 kg/kW
Total Propulsion System Mass	2,000 kg
Spacecraft Structure	3,000 kg
Science, Bus, Nonpower And Nonpropulsion Mass	6,000 kg
Total Mass	21,000 kg
30% Contingency	6,300 kg
Total Dry Mass With Contingency	27,300 kg
Propellant Mass	25,000 kg
Tankage Fraction	0.15
Tank Mass	3750 kg
Total Wet Mass With Contingency	56,050 kg

Table 2. EP Thruster/Systems TRL Characterizations

Thruster Type	Propellant	Power (kW)	Specific Impulse (s)	TRL Level **				Reference***
				Thruster	PPU	Feed System	Total System	
Ion	Mercury	201	8770	3/4	2	6	2	NASA TM X-73554
Ion	Xenon/Krypton	20	4500	4/5	2	6	2	CPTR 96-64
Ion	Xenon	25	8000	3/4	2	6	2	AIAA 2003 - 5279
Hall	Bismuth	32	8000	3	2	2	2	AIAA 2002-0348
Hall	Xenon	30	3160	3/4	2	6	2	AIAA 99-2949
Hall	Xenon	72	2747	4/5	2/3	6	2/3	NASA TM 2002-211969
Hall	Xenon	97	3800	4/5	2/3	6	2/3	GRC In-house Test (unpublished)
MPD*	Hydrogen	1000	10000	3	2	2/3	2	Journal of P&P, Vol. 17, No. 5
MPD	Hydrogen	22	5800	3	2	3	2	AIAA 88-3211
MPD*	Hydrogen	1600	6000	3	2	2/3	2	AIAA 88-3211
PIT	NH3, N2H4	40	2500	3/4	2	3	2	AIAA 99-2872
MPD	Ammonia	90	2500	3	2	3	2	AIAA 88-3211
MPD	Hydrogen	130	3500	3	2	3	2	AIAA 91-3568
MPD*	N2+2H2	900	1900	3	2	2/3	2	AIAA 91-3568
MPD*	Argon	4000	1400	3	2	2/3	2	AIAA 88-3211
MPD*	Argon	790	1500	3	2	2/3	2	AIAA 91-3568

* Pulsed – Pulsed MPDs should be of a lesser TRL level since continuous devices will be needed.
**Many are 3/4 since PPUs; feed systems not yet developed
***Abbreviations –

- AIAA: American Institute of Aeronautics and Astronautics
- CPTR: Chemical Propulsion Technology Review (by Chemical Propulsion Information Agency)
- GRC: Glenn Research Center
- MPD: magnetoplasmadynamic
- P&P: Propulsion and Power
- PIT: Pulsed Inductive Thruster
- PPU: Power Processing Unit
- TM: Technical Memorandum

The study phase must provide the following:

- A review of current thruster and AEP system technology SOA and technology challenges that must be overcome to advance the AEP system at least one TRL (include available test data and published reports);
- A development roadmap from development start to engineering model hardware completion with a timeline, milestones, TRL advances, and estimated costs;
- A conceptual design (including descriptions of AEP system elements) and supporting analysis of the proposed AEP system for potential follow-on work;
- A detailed test plan of how AEP thruster system performance will be verified for potential follow-on work including any special facility requirements; and
- A model contract for potential follow-on work.

Milestones shall address specific technology challenges and clearly define the impact on the program if they are missed. The development plan shall include identification of development risks, likelihood and consequence of their occurrence, and a risk mitigation plan. In addition, the study phase must provide the anticipated key electric propulsion system characteristics and benefits (with supporting analysis) associated with development and utilization of the proposed AEP system over ion and Hall EP technology as applied to interplanetary robotic exploration. Benefits provided should address advancements in one or more of the following: improvements in system performance, reduced system mass/volume, improved system reliability, and/or reduced cost. If applicable, environmental issues and potential for spacecraft contamination should be addressed.

Efforts to be undertaken after the base period of performance should address any unique component or system subscale laboratory tests required and full-scale laboratory tests of AEP thruster concept at the component or breadboard level to validate the ability to meet the above performance goals, with exception of lifetime testing. Although lifetime testing is not required, adequate analysis and testing to validate the analysis should be performed to provide enough information to assess lifetime capability and to identify and address technology challenges associated with meeting lifetime requirements.

Each submitted proposal must address only <u>one</u> thruster concept. There is no restriction, however, on the number of proposals that may be submitted by a given organization either by itself or as the lead of a team of organizations. Also, if the proposal duplicates work already being funded or selected for funding by Project Prometheus or other NASA programs, or offers only marginal/incremental improvements over ongoing NASA EP activities, NASA reserves the right not to consider the proposal further.

Teaming arrangements of all kinds by all types of proposing organizations, including nonprofit and for-profit, private, and Governmental are encouraged. If a non-NASA organization wishes to team with a NASA Center, such negotiations <u>must</u> be accomplished <u>prior</u> to submission of the proposal, and all costs associated with the intended activities at that NASA Center <u>must</u> be included in the cost section of the proposal. Note that no preference will be given to proposals that seek to team with a

NASA Center, nor for proposals that come from a NASA Center. For those wishing to consider teaming with a NASA Center the points of contact are:

NASA Glenn Research Center (GRC):	John Hamley (216/977-7430) John.A.Hamley@nasa.gov
NASA Johnson Space Center (JSC):	William Sherborne (281/483-2015) William.D.Sherborne@nasa.gov
NASA Marshall Space Flight Center (MSFC):	Timothy Ezell (256/544-3620) Timothy.G.Ezell@nasa.gov
NASA Jet Propulsion Laboratory (JPL):	Ron Reeve (818/393-4156) Ron.Reeve@jpl.nasa.gov

2. Background

2.1 Project Prometheus

NASA's Project Prometheus, the Nuclear Systems Program, is an advanced research and development program that includes evaluation and development of space nuclear power and propulsion systems that would enable a new class of demanding, high priority science exploration solar system missions not possible with current propulsion and power technologies. One near-term focus of Project Prometheus is to conduct advanced technology research and development in the areas of reactor power systems (1 to 4 MW thermal), power conversion systems (100 to 300 kW electric), and electric propulsion systems in support of NASA's first proposed Project Prometheus mission, the Jupiter Icy Moons Orbiter, and other revolutionary, solar system missions that could follow. The more advanced applications that could follow these first near-term NEP applications, are expected to require very high power electric propulsion thrusters in the range of 100 to 250 kWe with specific impulses of 4,000 to 10,000 or more seconds, and that are lower mass than the current technology under development. (Far-term nuclear propulsion applications may require even higher power engines, 1 MWe or more, much less massive systems, and even higher specific impulses.) These very high power electric propulsion performance goals, if met, could allow reduced trip times, lower mass, less complex, more reliable, and lower cost science missions to the outer planets and other solar system destinations. This AEP Technologies program is the first of what is anticipated to be a series of solicitations to support advanced nuclear electric propulsion technologies for Project Prometheus.

2.2 Potential AEP Applications

NEP applications that either require short flight times or deliver larger payloads than the first near-term applications may require very high power levels in the range of 250 to 500 kWe. Some advanced, very high power applications that could benefit from these

AEP technologies include a Neptune/Triton system orbiter, Saturn/Titan system orbiter, outer Solar System (Europa, Titan, or/and Neptune) sample return spacecrafts, Thousand Astronomical Units (1000 AU) or Gravity Lens (500 AU) spacecrafts, and/or Interstellar Precursor spacecraft. In the far-term, and using even higher power systems (>1 MWe), advanced NEP systems with even more highly developed AEP systems could be suitable for Mars Cargo and/or Mars Piloted applications.

3. Programmatic Information

3.1 General Provisions

All activities selected through this AEP Technologies program will be funded solely through multiyear contracts having a base period of performance of six months or less, with one year options for extensions up to maximum of three years. Proposals for efforts greater than six months must be structured with a six month initial period, with options for extension in time increments not to exceed one year each. Proposals should cover all option periods that the proposer intends to compete for under this NRA. The total proposed period of performance may not exceed three years. Proposals must define clearly measurable milestones (a minimum of two per fiscal year or partial fiscal year increment) to be achieved in order to justify continuation of funding. Funding approval for the subsequent year will be based on achievements toward milestones for the base performance period and the continued program needs and funds thereafter. Exercise of contract options will be based on performance and the availability of funds in future years, and there is no guarantee that any options will be funded for the remaining proposed period of performance.

The following budget information is tentative, subject to the availability of funds and outcome of proposal evaluations, and provided for planning purposes only:

> The anticipated budget for this NRA is expected to be as much as $0.8M for FY 2004, and between $1.5M to $2.5M in each of the following years. Typical funding awards for the base performance period are expected to range from $250K to $400K per proposal, with an expected total of 2-3 awards for FY 2004. NASA reserves the right to not select any proposal for this NRA solicitation.

3.2 Schedule

The schedule for proposals for this opportunity is:

Release Date:	January 23, 2004
Notice of Intent to Propose Due Date:	February 23, 2004
Proposal Due Date:	March 22, 2004

3.3 Evaluation Criteria

The evaluation criteria contained in Appendix C, Section C.2, of the *NASA Guidebook for Proposers* (see further below) shall be used to evaluate submitted proposals. Note that although the three principal evaluation factors are roughly of equal weight, the "Intrinsic Merit" factor is the most important of the three principal factors. With Merit" factor, the "Technical Merit" part shall specifically include the realism and reasonableness of the proposed AEP systems improvements/advancements and development/test plans.

3.4 OSS Education and Public Outreach (E/PO) Program

Consistent with Section 3 of the *Summary of Solicitation* of this NRA, OSS policy strongly encourages participation by the space science and technical community in education and public outreach activities with the goal of enhancing the Nation's formal education systems and contributing to the broad public understanding of science, mathematics, and technology. It should be noted that education is now one of the core missions of NASA. The baseline policy given in the *Summary of Solicitation* is that proposals for E/PO activities are voluntary on the part of the selected investigators, and this policy is applicable to this AEP Technologies program activity. Consistent with the nature of this opportunity, proposers should consider whether there may be unusual opportunities for technology or engineering education associated with a selected investigator's engineering and technology development efforts that could be of special interest to the public and educational community. In order to allow for E/PO activities that are appropriately scaled to the larger awards contemplated for the Project Prometheus Program element, the policy for E/PO activities is hereby amended to allow budgets of up to 5% of the proposed research activity rather than being capped at $15K per year as specified in the *Summary of Solicitation*. Please note that proposals for all E/PO activities will not be solicited until selections for this NRA are made. It should also be noted that an overarching program-level Project Prometheus E/PO program is being planned and E/PO activities undertaken by individual Investigators will be coordinated with this umbrella program.

3.5 Proposal Preparation and Submission Information

IMPORTANT INFORMATION

As discussed in the *Summary of Solicitation* of this NRA, NASA's Office of Space Science (OSS) is now using a single, unified set of instructions for the submission of proposals. This material is contained in the document entitled *NASA Guidebook for Proposers Responding to NASA Research Announcement–2003* (or *NASA Guidebook for Proposers* for short) that is accessible by opening URL http://research.hq.nasa.gov, and linking through the menu item "Helpful References," or may be directly accessed online at URL http://www.hq.nasa.gov/office/procurement/nraguidebook/. This NRA's *Summary of Solicitation* also contains the instructions for the electronic submission of an optional *Notice of Intent* (NOI) to propose and the proposal

Cover Page/Proposal Summary, which now also includes the required *Budget Summary*, and the mailing address for the submission of a proposal.

For questions regarding foreign company participation, refer to Sections 1.6 and 2.3.11(b) (vi) and (vii) of the *NASA Guidebook for Proposers (2003 version)* and in its Appendix B, *Instructions for Responding to NASA Research Announcements*, Section (l). Pursuant to NASA Federal Acquisition Regulation (NFS) 1835.016-70 (a)(3), NASA funding may not be used for subcontracted foreign research efforts. Direct purchase of supplies and/or services that do not constitute research from non-U. S. sources by U.S. award recipients is permitted.

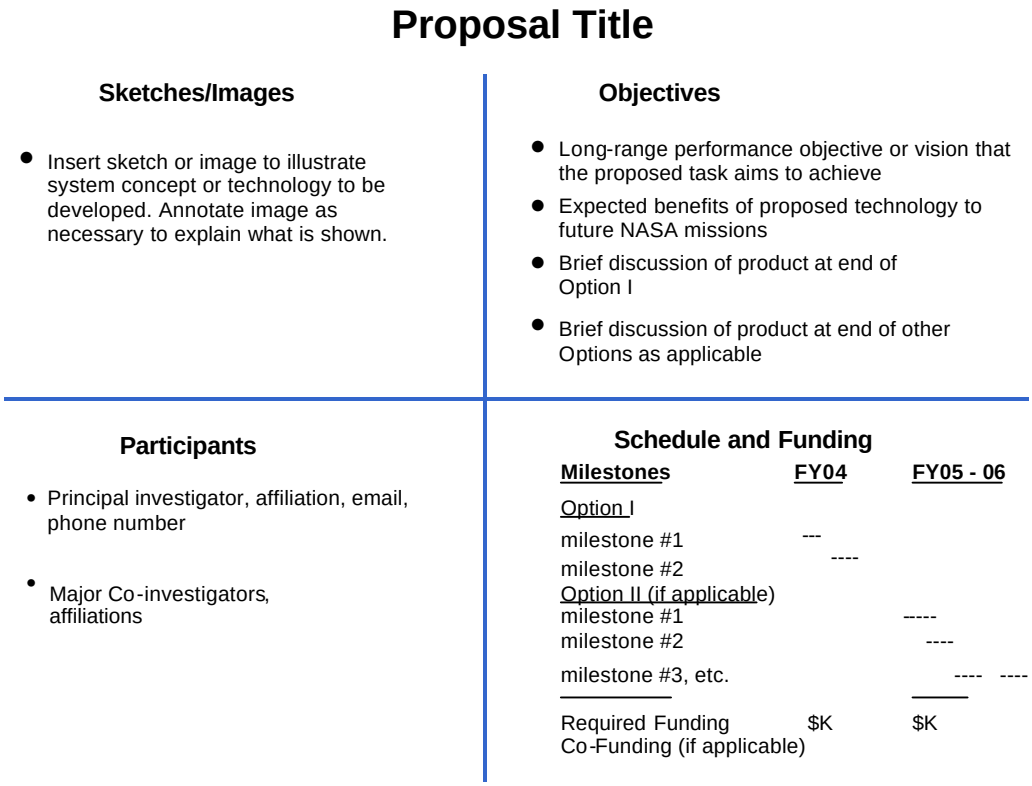
Note: In addition to the page limitations stated in Section 2 of the *NASA Guidebook for Proposers* for the various sections of a proposal, AEP Technologies proposals must also contain a Statement of Work (SOW) to be performed, not to exceed three pages in length, which is to be inserted directly after the "References" section of the proposal. A quad chart in Microsoft PowerPoint format (template contained in Figure 1 below) is also be required.

NASA MSFC will have responsibility for implementation of the contract awards under this amendment. Those who receive an award shall provide initial task inputs to the appropriate implementation manager and submit monthly updates pertaining to technology readiness levels, technical performance measures (TPMs), resources, schedule, and milestones. Additionally, a monthly status submittal of accomplishments, issues, and upcoming events is required. A Final Report per contract phase is required summarizing all work performed in that phase suitable for use by a Government-led team for evaluation of progress on the AEP Technologies.

Since awards to be made through this program element will be contracts with options to continue on an annual basis, there will be additional programmatic requirements including reporting, data base entries, and reviews. Other reporting requirements include providing final reports in a format suitable for publication as a Contractor Report or equivalent government publication. Descriptions of these types of reports/publications can be found at: http://nodis3.gsfc.nasa.gov/library/displayDir.cfm?Internal_ID=N_PG_2200_002A_&page_name=main. Finally, all selected participants in this program will be required to develop and present a technical paper at a suitable technical conference and/or publish their results in an appropriate technical journal.

Figure 1. Quad Chart Template

The following is a template for the quad chart that is required for each proposal. It is to be submitted in addition to the *Proposal Summary* contained on the Web-submitted *Cover Page*.



Reviews will be held in conjunction with project level or task milestones and completion of contract phases, with a minimum of initial, annual, and final reviews. These reviews will document the progress against TPMs that will be established prior to award, and other performance metrics such as, deliverables, test results, cost vs. budget statistics, and adherence to planned schedules.

Questions concerning this AEP Technologies program may be directed to the Nuclear Propulsion and Vehicle Systems Program Executive:

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