D.2 CRITICAL ISSUES IN ELECTRIC PROPULSION

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 critical areas in electric propulsion (EP) thruster technologies that have the potential to dramatically improve thruster life or otherwise significantly increase the performance and usefulness of EP thrusters. The goal of this Critical Issues in Electric Propulsion (CIEP) research and development effort is not to develop flight-qualified hardware, but to advance electric propulsion technologies that are critical to improvements in electric propulsion applicability to future NASA space exploration missions. EP thrusters are currently in use for station-keeping and have recently been demonstrated as primary propulsion units. Broader use of EP can be enhanced by technologies that address critical technology issues, such as reduction or elimination of wear mechanisms, longer thruster life, ability to vary thrust, improved performance, and reduced weight across the range of EP specific impulse and power. NASA seeks proposals that advance selected EP thruster technologies that address these critical issues, resulting in measurable and validated improvements beyond current EP thruster state of the art. Representative EP system information for various types of EP systems, including references, is provided in Table 1 below.

This NRA solicits research and development activities that lead to validated performance advancing thruster state of the art in the following critical areas, via breadboard EP thruster system demonstration in a laboratory or relevant environment, or an equivalent validation method:

- Increase in EP thruster lifetime in the range of 5 to 15 years. Examples of critical life extension areas:
  - Reduction or elimination of component wear mechanisms associated with acceleration or ionization.
  - Innovative thruster concepts that reduce or eliminate wear mechanisms across the thruster system.
  - Innovative proven approaches that simply and/or accelerate validation and flight qualification of 5 to15 year life EP thrusters prior to flight use.
- Reduction of EP thruster weight for high specific impulse and long-life thrusters.
- Ability to vary thrust (and specific impulse) for missions requiring high specific impulse for most of a mission, but relatively higher thrust for other portions of the mission.
- Maintenance or improvement of 5 to 15 year life EP thruster performance using alternative, more advantageous EP fuels (e.g., fuels that are lower costs, more available, easier to store, more compatible).

Note that while laboratory research, hardware development, and testing are expected to be needed to successfully demonstrate technology advancements relevant to these goals, analytical modeling is not precluded.

A major objective of this program is to conduct studies to be completed within six months of award (base period of performance; see further below) that lead to validated EP thruster system performance and/or capabilities improvements within three years in one or more of the critical areas listed above. Proposals that develop EP thruster system components will be considered as long as the component technology benefit can be shown to have benefits at the thruster system level. Subscale EP hardware demonstrations will also be acceptable for consideration provided that the proposal clearly delineates how the results can be accurately and convincingly scaled to full size EP thruster systems. However, proposals that develop power processing unit or fuel delivery components will not be considered. Also, 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.)

The study phase for tasks selected through this program must provide the following:

- A review of current EP thruster technology state-of-the-art and technology challenges that must be overcome to advance thruster technology in the proposed critical area by at least one TRL (include available test data and published reports);
- A development roadmap from start to engineering model hardware completion and testing with a timeline, milestones, TRL advances, and estimated costs;
- A conceptual design and supporting analysis of the proposed thruster improvement system and/or laboratory test hardware for potential follow-on work; and
- A model contract for potential follow-on work having milestones that address specific technology challenges and clearly define the impact on the program if they are missed.

The proposed development plan shall include identification of development risks, the likelihood and consequence of their occurrence, and a risk mitigation plan. In addition, the study phase must provide the anticipated key electric propulsion thruster improvement characteristics, enhanced EP capabilities, and other benefits (with supporting analysis) associated with application to interplanetary robotic exploration. Enhanced EP capabilities and other benefits provided should address advancements in one or more of the following: (i) improvements in thruster life, (ii) simpler and/or faster validation and flight qualification for long-life EP thrusters, (iii) improvements in thruster performance, (iv) reduced thruster mass/volume, (v) improved thruster reliability, or (vi) reduced cost. If applicable, environmental issues and potential for spacecraft contamination should be addressed.

Each submitted proposal must address only one thruster technology, although there is no restriction 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. However, 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 on-going 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 must be accomplished prior to submission of the proposal, and all costs associated with the intended activities at that NASA Center must 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. However, for those wishing to consider teaming with a NASA Center the points of contact are:

NASA Glenn Research Center:	Robert Jankovsky (216 977-7420) Robert.S.Jankovsky@nasa.gov
NASA Johnson Space Flight Center:	William Sherborne (281 483-2015) William.D.Sherborne@nasa.gov
NASA Marshall Space Flight Center:	Timothy Ezell (256 544-3620) Timothy.G.Ezell@nasa.gov
Jet Propulsion Laboratory:	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 (1-4 MW thermal), power conversion systems (100-300 kW electric [kWe]), and electric propulsion systems in support of NASA's first proposed Project Prometheus mission, the Jupiter Icy Moons Orbiter (JIMO), and other revolutionary, solar system missions that could follow. Advanced applications that could follow these first near-term applications are envisioned to require a range of power levels, from sub-kilowatts to megawatts. Most applications, regardless of power level, demand thruster lifetimes of 5 to 15 years, and specific impulses ranging from 5,000 to 15,000 seconds.

2.2 Potential Advanced Thruster Applications

Electric propulsion is seen as highly desirable for deep-space missions through its promise to deliver large changes in velocity at very high specific impulse. The emphasis on long thruster life in this NRA derives from the expectation that future EP applications will place even further demands on this advantage of high propulsive energy for planetary robotic missions. Outer planet rendezvous and sample return missions represent possible applications, as well as extra-solar system probes and interplanetary precursors. While lifetime is a predominate critical issue for these advanced applications, some involve significant spacecraft time in large gravity wells, where increased thrust levels could be highly desirable. Spacecraft masses could range from very large, tens of metric tonnes for intensive science and sample return missions, to small, tens of kilograms (or less) for solo or fleet applications of single-purpose probes to targets ranging from near Earth asteroids to Mars and beyond.

3. Programmatic Information

3.1 General Provisions

All activities selected through this CIEP 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 anticipated budget for this NRA is expected to be as much as $0.7M for FY 2004, and after FY 2004, between $1.6M to $2.5M per year. Typical funding awards for the base performance period are expected to range from $250K to $400K per proposal, with an expected total of two to three awards. NASA reserves the right to not select any proposal for this NRA solicitation.

3.2 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. Although the three principal evaluation factors are roughly of equal weight, the “Intrinsic Merit”

factor is the most important of the three principal factors. Within the "Intrinsic Merit" factor, the "Technical Merit" part shall specifically include the realism and reasonableness of the achieving the proposed CIEP improvements/advancements using the proposed development and test plans.

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

The baseline policy given in Section I(b) of 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 CIEP 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 this program, 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 selected through this CIEP program will be coordinated with this umbrella program.

3.4 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 – 2004* (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 a *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 please refer to sections 1.6 and 2.3.11(b) (vi) and (vii) of the *NASA Guidebook for Proposers* and in its Appendix B, 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, CIEP 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 of the Appendix of this Amendment) is also required.

NASA Glenn Research Center will have responsibility for implementation of 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 that summarizes all work performed in that phase suitable for use by a government-led team for evaluation of progress on the CIEP Technologies.

Since awards to be made through this program will be contracts with options to continue on an annual basis, there will be additional 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.

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 CIEP Technologies program may be directed to the Nuclear Propulsion and Vehicle Systems Program Executive**:**

Mr. John Warren
Nuclear Systems Program Office
Office of Space Science
Code SN
NASA Headquarters
Washington, DC, 20546-0001

Telephone: (202) 358-4415
Facsimile : (202) 358-4037
E-mail : John.W.Warren@nasa.gov

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*. It does not count against the page count for the proposal.

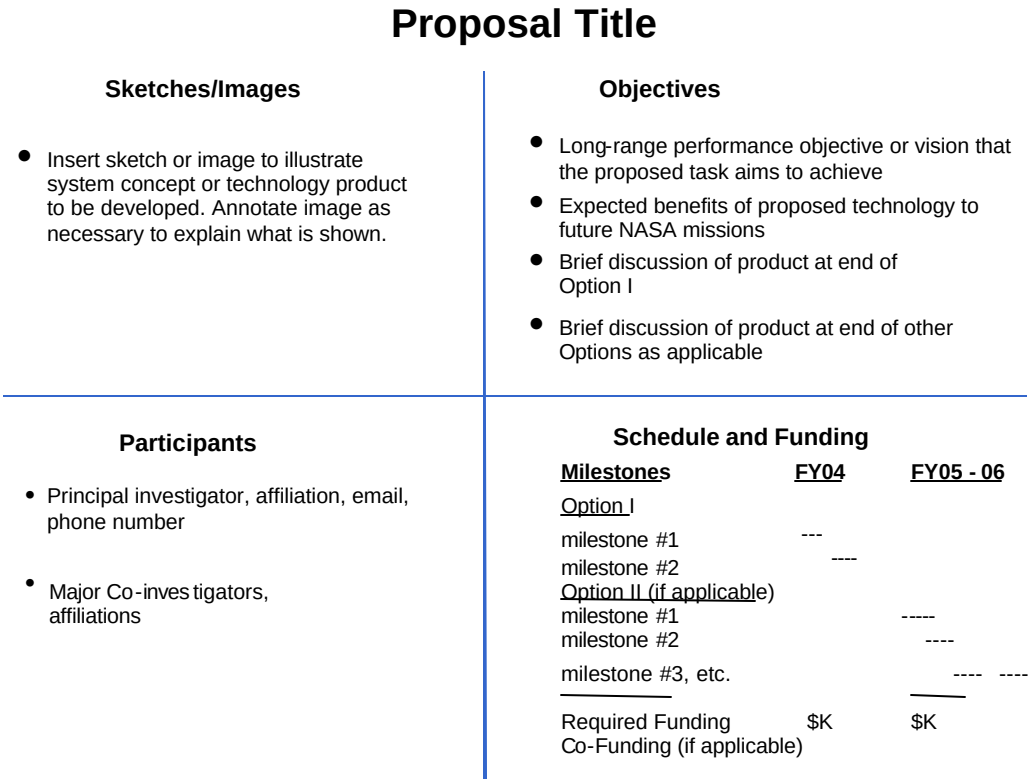

Table 1. Electric Propulsion Thruster/Systems TRL Characterizations.

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