Appendix A

Technology Infusion Study Questions

As mentioned in the Introduction, the primary objective of the PSD Technology Infusion Study, and, therefore, this RFI, is to provide PSD with recommendations on how to effectively infuse new spacecraft systems technologies which it develops into future competed missions enabling increased scientific discoveries, lower mission cost, or both.

Please respond to the following questions regarding planetary science missions in general and/or the most recent New Frontiers and Discovery Announcements of Opportunity (AOs). If you are commenting on a specific AO, such as Discovery, please specify that in your response:

1) What do you perceive are the barriers to new technologies being integrated into mission concepts and proposals? What do you recommend to reduce those barriers?
2) What improvements can NASA implement that can facilitate improved communication regarding new technologies, their capabilities, and maturity that would benefit science exploration?
3) Was the type and amount of information provided regarding the technologies adequate for an AO proposal development? What do you suggest to improve the information flow?
4) What should be the minimum technology maturity level required before a new technology is recognized as viable and ready for infusion? How should the maturity level be assessed and by whom? What data is required to make this assessment and what can NASA provide to assist in the decision making process? Can you provide any examples of when the assessment of maturity stopped a proposal from being developed or submitted?
5) Can you discuss how your company's decision process to invest in developing an AO proposal including a new technology is affected by the technology readiness level? What is recommended to reduce the risk and barriers at this phase of the life cycle?
6) Please discuss the benefits and limitations of the different technology incentivization methods previously used in the New Frontiers 3 and Discovery 12 AO's? How can the technology incentivization methodology be improved?
7) How can NASA reduce real and perceived spacecraft system risks when using new technologies?
8) From the end user perspective, are there any other viable options for improving technology infusion that NASA could consider?
9) Is NASA working on the right portfolio of technologies to benefit science exploration? What is missing and what may not be needed?
10) How long before the AO release does the community need to understand the incentivization method and the technologies being offered?

11) Please provide any additional comments regarding reducing the barrier of technology infusion.

Appendix B

In-Space Propulsion Technology Program Technology Infusion Study Questions

The primary goal of the ISTP is to provide propulsion technologies that enable or enhance science exploration. To that end, please answer the following questions for any of the following In-Space Propulsion Technologies of interest or relevance to your organization:

A) NASA Evolutionary Xenon Thruster (NEXT)
B) Advanced Materials Bi-propellant Rocket (AMBR)
C) Aerocapture maneuver, and/or aeroshell hardware technologies (TPS and hot structures)
D) Hall Effect Electric Propulsion

1) Is your organization considering using the above technologies for future missions and/or uses? If so, for what types of missions and/or uses? Are there any technology gaps to be addressed unique to these types of missions? Would conducting a "competed mission capability enhancement" study on ISPT products similar to the Discovery Scout Mission Capability Enhancement (DSMCE) studies for use of the Advanced Stirling Radioisotope Generator (ASRG) help with the understanding and infusion of these technologies, and if so, how?

2) In your opinion, what minimum level of technology readiness, or other factors, would be required for the above technologies to be adopted by an end user for future missions? In addition, specifically address, as appropriate:
    a. Does NEXT need to have a fully TRL6 validated PPU and DCIU before being considered for a mission?
    b. What additional development and qualification activities are required to enable AMBR to be included into future design concepts and missions?
    c. Do the aerocapture maneuver and related technologies require a flight demo in order to be viable to be incorporated into future concepts and designs?

3) What are the high-risk areas for the above technologies that require further mitigation?
    a. Are the interfaces sufficiently defined and provided for your implementation needs?
    b. What is an acceptable risk tolerance at the proposal stage of the life-cycle?
    c. What data is required to provide risk closure?

4) Regarding technology incentive approaches for the above technologies:
    a. What are the minimum additional technology development milestones that must be met before your organization would consider proposing the above technologies without a cost incentive? Please be as specific as possible for individual subsystems.
    b. If the above technologies are not matured further beyond this year, would cost sharing of the remaining development be sufficient for adoption of the technology

in future proposals? What level of cost sharing would allow inclusion into your proposal?

c. Aside from offering these technologies as GFE, how would the incentivization method influence your decision to utilize the technologies listed above?
d. If these technologies are offered as GFE, do you think there is sufficient maturity to include it in an AO response?

5) Are there other considerations/subsystem technologies/system implications (spacecraft bus or mission operations) that may have impacted your decision and/or risk posture regarding the infusion of these technologies? Any quantifiable feedback would be appreciated. For example:
    a. NEXT: Operations cost, increased solar array cost, operational complexity, etc…
    b. AMBR: Increased thermal interface concerns, decreased feed system pressure margin, operational complexity, etc…
    c. Aerocapture: Increased packaging complexity, cruise science opportunities, lack of expertise, etc…

6) Please discuss the following alternative technology considerations.
    a. Is Aerocapture enabling for mission(s) under consideration by your organization, or do you have an alternative/preferred orbit capture option? What is this method and why is it preferred? Are the potential benefits of Aerocapture sufficiently defined and advertised, for you to be able to assess its influence on your mission? Are the potential benefits of new aeroshell materials sufficiently defined and advertised for you to be able to assess their influence on your mission?
    b. If you evaluated the AMBR engine, did you down select to an alternative due to cost, risk, performance, etc? If there were other factors, please identify and describe those factors.
    c. Would you recommend another higher priority electric propulsion capability investment for Discovery and New Frontiers class missions other than NEXT? Specifically, if a ~4kW-class Hall electric propulsion system for planetary missions would be available for the next Discovery AO ($\geq$ TRL6 by PDR), would it be proposed for mission(s) under consideration? What science mission needs would this system capability address?

7) Please discuss the impact the four ISPT technologies could have on achieving NASA's science goals and objectives
    a. How much mission pull is there for the technology and for what types of missions are they considered enabling or enhancing?
    b. Does this change with the customer (i.e. NASA SMD, NASA non-SMD, DOD, Commercial)?

8) What can be repurposed from the existing ISPT program? For example, much of the thermal protection system (TPS) work from Aerocapture may be used for other entry vehicle purposes (EDL, EEV, or probes)?

9) Are ISPT's existing analytical tools (Low Thrust Trajectory Tools (LTTT), Multi-mission Systems Analysis for Planetary Entry (M-SAPE), Propulsion Sizing Tool, etc…), sufficient for end user needs?

Other Spacecraft Technology Questions

1) What spacecraft bus technologies would be of the most interest to the planetary science mission community?

2) Are there cost effective spacecraft bus technologies that can be adapted from commercial or DoD applications?

3) Do you have any suggestions of other customers for spacecraft bus technologies relevant to NASA planetary missions?

Appendix C

Radioisotope Power Systems Program Technology Infusion Study Questions

1) What considerations contributed to your decision to use an ASRG in your proposal? Please include availability of ASRG information in your answer. Was the ASRG information in the Discovery Program Library available early enough for your development cycle and/or schedule?
2) How did the Discovery Scout Mission Capability Enhancement (DSMCE) studies impact the evaluation of the ASRG technology in mission concept planning and the development of a proposal in response to the Discovery 12 AO?
3) Please comment on the AO library as the repository of ASRG AO information: the information data structure used, data updates, the ease of finding information sought, and the consistency of information. Did the Discovery Program Library contain sufficient detail into the more salient aspects of the ASRG?
4) The Discovery Program Office, RPS Program Office, ASRG Project Office, Department of Energy, and Launch Approval Engineering were all involved in the proposal process. What interaction did you have with each of these groups? How useful were these interactions? Were the frequency, timing and interchange of information sufficient? What suggestions would you have to improve these interactions?
5) Did the Advance Stirling Radioisotope Generator Information Summary (7/7/2010), Updated 7/30/2010; The ASRG User ICD (6/9/2010), updated 7/19/11; and CDRL 7, ASRG System Specification (7/19/11) provide sufficient detailed technical insight into the ASRG design for your team? Please discuss these documents usefulness, clarity, level of detail, comprehensiveness, consistency and any issues you identified. What suggestions would you have to improve these documents?
6) Please comment on the adequacy of the models and supporting documentation provided. What additional models or improvement to the supporting documentation would you have found helpful?
7) Please comment specifically on the considerations and challenges encountered due to the unique aspects of using a radioisotope-based system. Specifically consider NEPA and Nuclear Launch Safety as well as integration and operational aspects. Please discuss the process used to educate your team in these areas. Also discuss the sufficiency, clarity, and usefulness of the information provided and the process used to convey this information. What, if any, suggestions do you have to improve the interchange and information?
8) Would you enumerate items, issues, and opportunities for improvement that would have enhanced your interactions with the ASRG Program/Project Team? Please identify areas where we could have made your proposal better, or your proposal generation process more efficient.
9) Please provide any additional feedback, positive or negative, that will help NASA improve future AO solicitations and processes involving radioisotope systems.

10) What was your general, overall assessment of your interactions with the ASRG Program/Project Team? What did you learn from this experience and what do you suggest for the future?

11) Please comment on any perceived or actual impacts resulting from the ASRG being designed in parallel to the AO process. Does this approach provide demonstrative or substantial benefits, including risk reduction? How mature does the ASRG technology need to be before being recognized as viable and ready for infusion by the end user? What suggestions would you have to improve this situation?

Appendix D

References and In-Space Propulsion Technology Program Technology Descriptions

References:

ISPT Web Site
http://spaceflightsystems.grc.nasa.gov/SSPO/ISPTProg/

RPS Website
http://rps.nasa.gov

Discovery Program Library
http://discovery.larc.nasa.gov/dpl.html

New Frontiers Program Library
http://newfrontiers.larc.nasa.gov/NFPL.html

NEXT Phase 2 Closeout Documentation and NEXT TRL Assessment (can be provided upon request)

Technology Descriptions:

NASA's Evolutionary Xenon Thruster (NEXT)

The NEXT (NASA's Evolutionary Xenon Thruster) Ion Propulsion System (IPS) is an advanced 7-kilowatt electrostatic xenon ion-thruster propulsion system developed for deep-space applications. The NEXT system development consists of a thruster, power processing unit (PPU) propellant management system (PMS), gimbal, and a digital control interface unit (DCIU) simulator. The thruster operates over an input power range of 0.5-6.9 kilowatts, produces a maximum specific impulse of 4190 seconds, a thrust range of 26-236 milliNewtons, and a maximum thruster efficiency of 71%. In an on-going long duration test, the thruster has demonstrated over >800 kg of xenon throughput, >45,000 hours, and >30 MN-second of total impulse. The PPU operates from 0.65-7.2 kilowatts and an input voltage range of 80-160 volts with a peak efficiency of 95%. The PMS provides the necessary xenon flows for operating the thruster. The gimbal provides the mechanical actuation authority needed to maintain thruster pointing through the spacecraft center of mass. The individual components have been tested in performance and appropriate environment and integrated into system-level demonstrations.

The incentive provided by SMD in the last Discovery AO was the following:

- Use of NEXT IPS components including the ion thruster, power processing unit, propellant management system, digital control interface unit and gimbal.
- The ion thruster and power-processing unit were critical components for the NEXT IPS. The NEXT thruster is manufactured by Aerojet, and the NEXT PPU is being developed by L-3 Communications.
- Alternate propellant management system (Aerojet), DCIUs, and gimbals were acceptable.

Advanced Materials Bipropellant Rocket (AMBR) Engine

The AMBR (Advanced Materials Bipropellant Rocket) is a chemical rocket that has developed and applied an improved material processing technique to the iridium/rhenium rocket chamber manufacturing. The result was a high performance (high specific impulse), higher thruster radiation, cooled rocket engine that fits the same physical envelope as the R-4D rocket engine and operates on NTO/N2H4 propellants. The rocket demonstrated a thrust of 140 lbf, a maximum specific impulse of 333 seconds, when operated with an inlet pressure of 250 psia and an oxidizer-to-fuel ratio of 1.1. The test campaign included baseline hot-fire testing, shock and vibration testing, post-environmental performance testing, and long-duration testing. The testing duration totaled more than 9100s, including 89 restarts and a single burn duration of 2700s.

The incentive provided by SMD in the last Discovery AO was the following:

- Use of the AMBR engine, which consists of injector, combustion chamber, and nozzle hardware. AMBR is manufactured by Aerojet.
- Given the intent of demonstrating the AMBR materials processing technique, the combustion chamber would need to be fabricated using the demonstrated iridium/rhenium El-form fabrication process.
- Alternate injector designs and alternate fuel/oxidizer combination (MMH/NTO) were acceptable.

Aerocapture

Aerocapture is the use of aerodynamic forces to slow an approaching vehicle and put it into a closed orbit about a planet. In contrast to aerobraking, aerocapture occurs in a single atmospheric pass, so orbit establishment is immediate. By accomplishing over 95% of the orbit insertion delta-V with drag, aerocapture saves significant propellant mass, allowing the use of smaller, more inexpensive launch vehicles, faster trip times, or increased payloads. The heating and aerodynamic loads on the spacecraft require that a heatshield, like that used for entry, descent and landing (EDL), be used for protection. The heatshield must also provide the aerodynamic shape required for autonomously controlling the vehicle to a specified target altitude upon exit, after which the heatshield is ejected and adjustments can be made to achieve the final orbit.

The incentive provided by SMD in the last Discovery AO were the following:

- Use of the aerocapture maneuver (guidance algorithm); flight software exists and could be provided by Ball Aerospace
- High-temperature aeroshell structure and TPS from ATK-Composite Optics and Applied Research Associates, Inc.
- Carbon-Carbon rib-stiffened hot structure aeroshell from Lockheed Martin Space Systems