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20 kWe NEP FLIGHT SYSTEM

NUCLEAR PROPULSION TECHNICAL INTERCHANGE MEETING

PLUMBROOK STATION

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20 kWe NEP FLIGHT SYSTEM

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STUDY BACKGROUND

- High Level Interest in Early Flight of SP-100 Based NEP System
  - OAST AA
  - Joint NASA/DOE Space Nuclear Power and Propulsion Team
- Mission Emphasis is Space Science
  - Planet, Asteroid Exploration
  - NASA User: Office of Space Science and Applications

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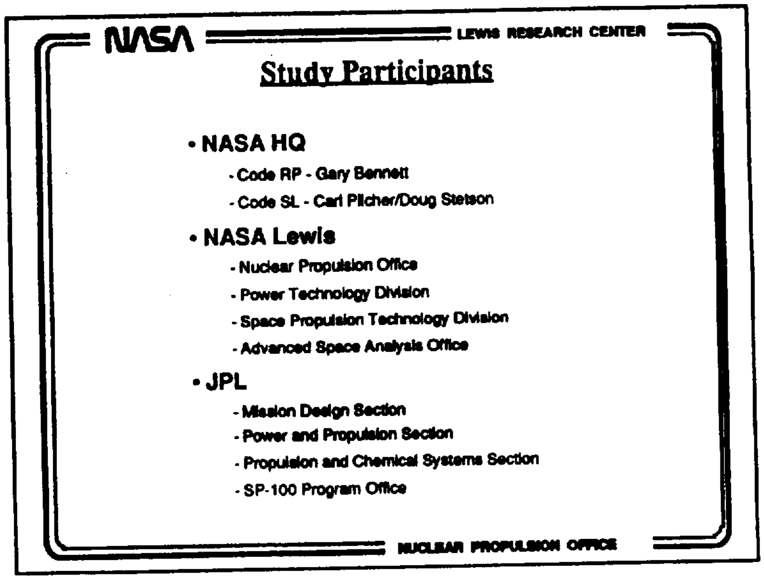
STUDY BACKGROUND

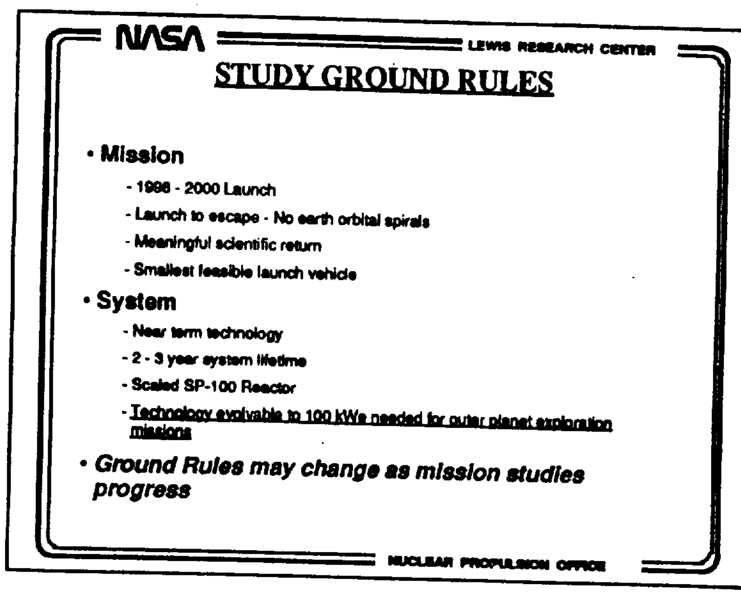
A low power near term NEP system has been proposed as a useful interim system for near term space exploration. Although the ultimate goal of a 100 kWe class, low specific mass for planetary exploration remains, application of the technologies that are currently mature to earlier missions of interest has grown at the higher levels of NASA. In response to this interest, a study of low power system and mission options has been initiated, with the Nuclear Propulsion Office serving to coordinate system activities. A nominal 20 kWe system using Brayton power conversion has been selected by the joint NASA/DOE Space Nuclear Power and Propulsion team; however, other power levels and system options will be considered. NASA's Office of Space Science and Applications has expressed interest in exploiting NEP's mission capabilities, both in the near term and for more difficult, later missions.

Technologies considered mature for this type of system are the SP-100 reactor, Brayton dynamic power conversion, and 30 cm ion thrusters, all of which have extensive ground demonstration backgrounds.



Study Participants

The full assessment of a 20 kWe NEP system and its applications has drawn together a team spanning NASA's Codes S and R, including experts from both Lewis Research Center and the Jet Propulsion Laboratory. The team includes mission planners, power system engineers, electric propulsion researchers, and program level managers. Mission design and analysis is primarily the responsibility of Code S, while system design and technology assessment is the responsibility of Code R.



STUDY GROUND RULES

The concept of a near term NEP flight and science mission is based on achieving certain goals in terms of timely delivery of scientific information as well as timely use of mature technologies. In this case, near term means a launch in 1998 to 2000. Some initial ground rules that have been imposed on the study to date are that the mission should leave Earth orbit, and gather data useful to space scientists. On a system level, a power level of 20 kWe and a lifetime of 3 years were mandated for initial studies. The combination of low lifetime and power leads to a mission requirement of launch to escape. In the interest of low cost and easier launch scheduling, expendable launch vehicles are assumed, up to and including a Titan IV/Centaur as the largest option. A further ground rule was that the technology used on this early mission has some bearing on the development of the ultimate 100 kWe outer planet systems.

These are initial ground rules, based on preliminary conceptions of mission performance. As more detailed analysis warrants, these assumptions can change to incorporate improved data.

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System Analysis Assumptions

- 10 - 50 kWe
- 3 year life
- 2000 V to load
- 15 m reactor-to-payload separation distance
- Payload radiation dose:
  - 1.0×10^{12} neutron/cm^2
  - 5×10^4 rad(Si) γ
- 17° shield half-angle
- 10% excess heat rejection capacity

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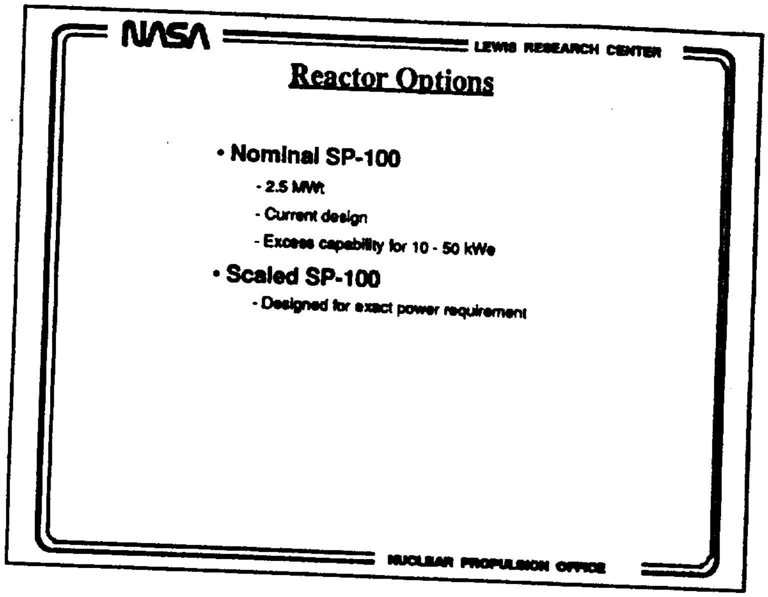
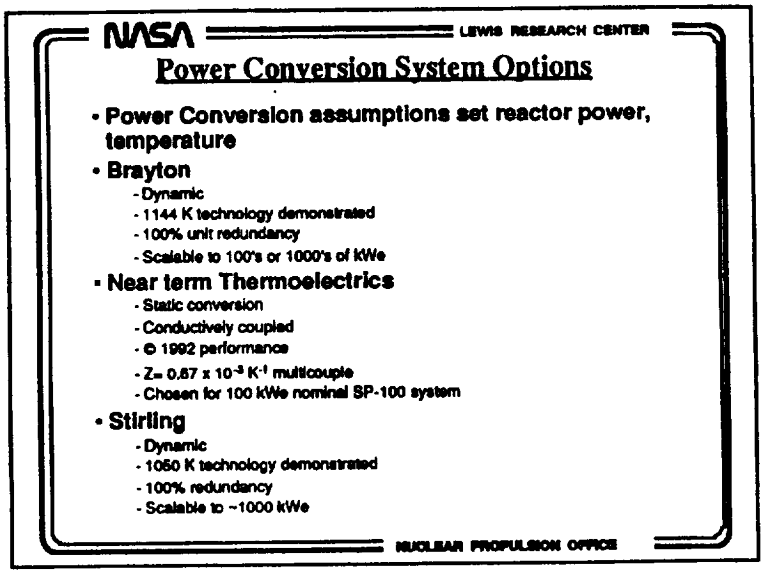
System Analysis Assumptions

System assumptions are shown above. Of primary importance are the separation distance and radiation dose constraints. These are lower than those identified for the 100 kWe SP-100 mission, impacting relative shielding mass. The lower doses are aimed at using near term electronics rather than radiation hard materials. In addition, the lower dosages may ameliorate interference of the power system with scientific instruments. The shorter boom length allows for greater ease of packaging and deployment in expendable launch vehicles. Improved system mass might be achieved through the use of a greater separation distance; however, this must be included in a detailed trade versus technology readiness and packaging concerns. The above assumptions were imposed on all systems designs, regardless of reactor or power conversion selection.



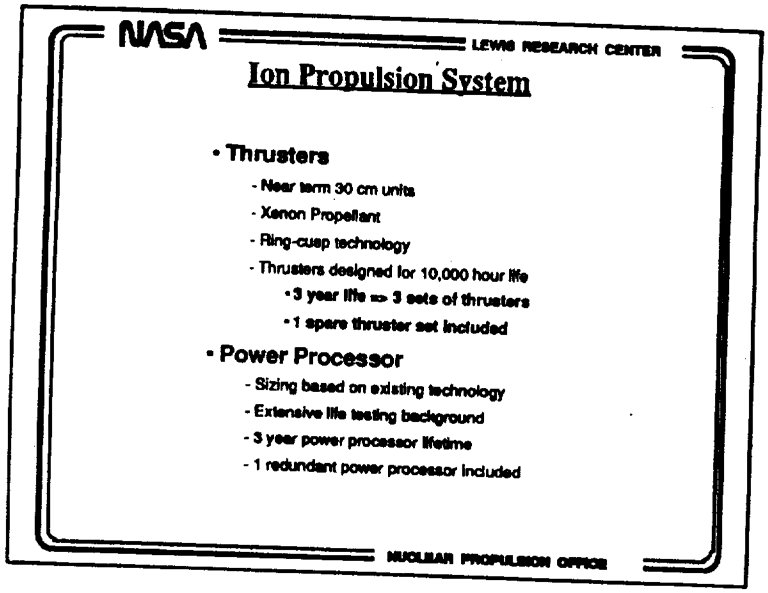
Reactor Options

Two reactor options were considered in these studies: a full power, 2.5 MWt SP-100 reactor, with excess capability for the low power system, and a scaled reactor designed for exactly the thermal power required for a given electric power output. Due to the desire to obtain a minimum mass system, the scaled option has been baselined; however, the full power option would provide experience in fabricating the same reactor that will be used in the later, 100 kWe planetary exploration system. These two options represent an additional trade which will have to be performed to determine the most effective development approach.



Power Conversion System Options

Three power conversion system options were considered: the baseline Brayton, near term thermoelectrics, and a near term Stirling system. The Brayton system is based on the Brayton Rotating Unit (BRU) developed and tested at NASA Lewis Research Center in 1966-1968. Lifetimes of up to 41,000 hours (>4.5 years) were demonstrated at 1144 K with this system. A system redundancy of 100% (1 spare power conversion unit) was assumed in mass estimates. Of the alternatives, the near term thermoelectrics is based upon interim technology thermoelectric elements, based on performance demonstrated in 1992. The thermocouples are the precursors to the elements that are to be used on the 100 kWe nominal system, maintaining an evolutionary link to the ultimate system. The Stirling option is based upon a low temperature technology that has been tested in the laboratory, although not to the level of the BRU.



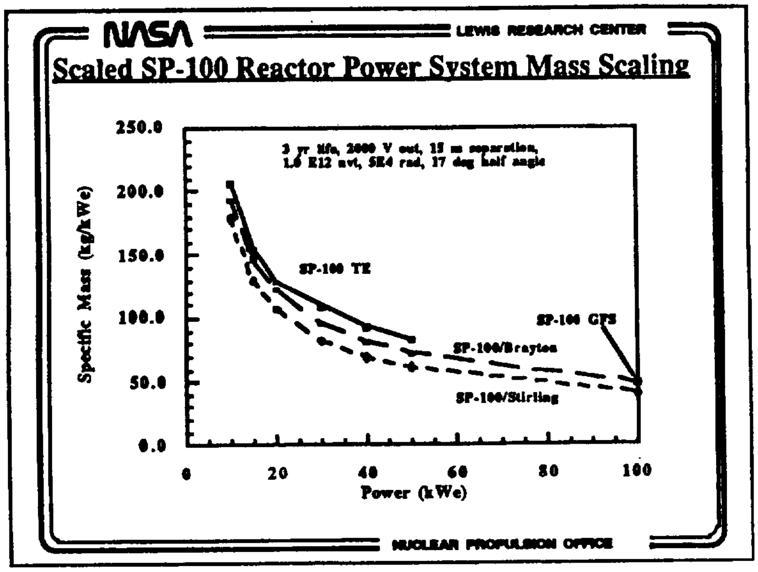
Ion Propulsion System

The electric propulsion system uses 30 cm diameter ion thrusters operating on xenon propellant. Thrusters of this size using xenon have been ground tested extensively, and the thruster designs build on flight testing and development of ion thrusters extending back to the 1960's. Life testing of these thrusters has identified regimes of operation to permit 10,000 hours life, and these regimes have been assumed in thruster system design. Performance parameters have been generated over a range of specific impulses for these thrusters, to allow flexibility in mission analysis and optimization. Thruster masses are based upon flight like thrusters that were constructed in 1992.

The assumed electric propulsion power processing electronics share a heritage with the thrusters. System mass estimates have been based on scaling equations taken from actual flight systems and designs. Power processors have demonstrated lifetimes more than adequate for the full mission life assumed in this study.

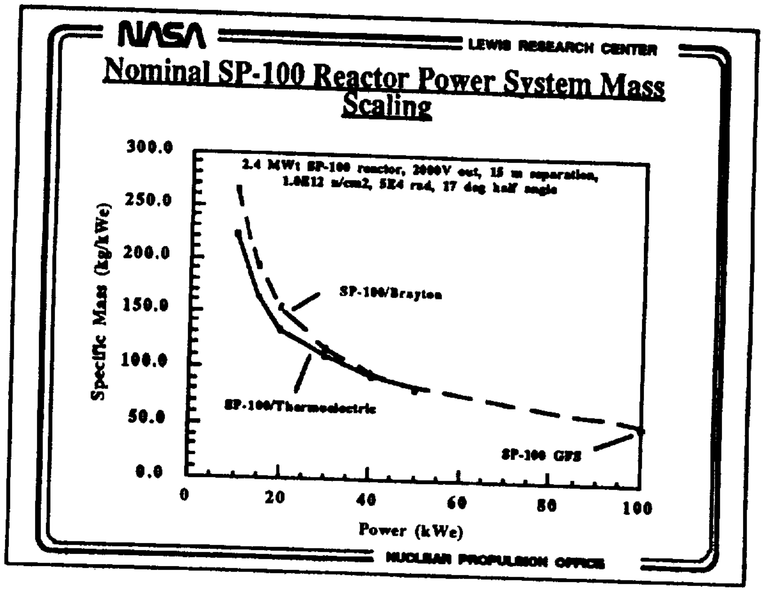
In order to meet system lifetime requirements, several sets of thrusters are required. Three years of life is 26,280 hours, requiring 3 sets of thrusters to ensure suitable lifetime. An entire redundant set of thrusters has been included in the system mass to provide an additional level of reliability. Each thruster in a set is assumed to have its own power processor; however, In the case of the power processor, a single unit should operate for the entire life of the mission. One set of spare units is included for additional reliability.

As mission analyses mature, the exact number of thrusters and power processors required will be determined and more exact system designs can be developed.



Scaled SP-100 Reactor Power System Mass Scaling

Results of power system analysis are shown above for the case of the scaled SP-100 reactor. Specific mass includes boom and transmission to the spacecraft bus. Electric propulsion specific mass is not included, as this will vary with specific impulse as well as power. A significant penalty in specific mass is seen at power levels below 30 kWe, due to the limits in scaling of the reactor and shield. However, some launch vehicle payload mass and volume considerations may restrict the system to these lower powers.



Nominal SP-100 Reactor Power System Mass Scaling

Comparable results are shown for the case using the nominal 2.5 MWt reactor. At 20 kWe, there is approximately a 25 kg/kWe penalty for using the larger reactor. Again, mission and development cost analyses are needed to determine the impact of this difference on the implementation of the early NEP system.

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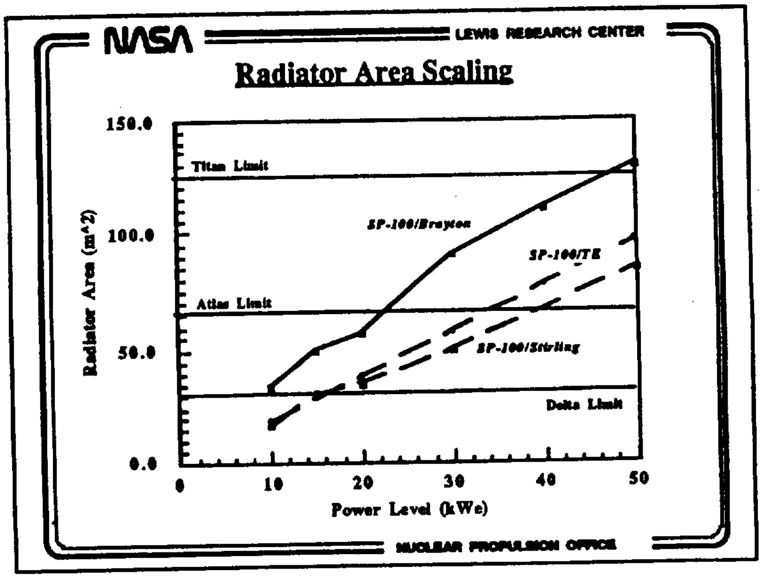
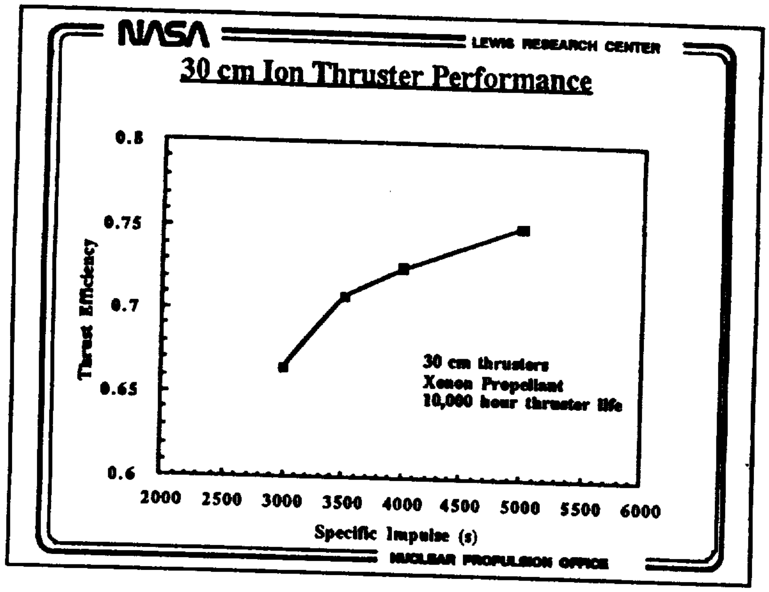


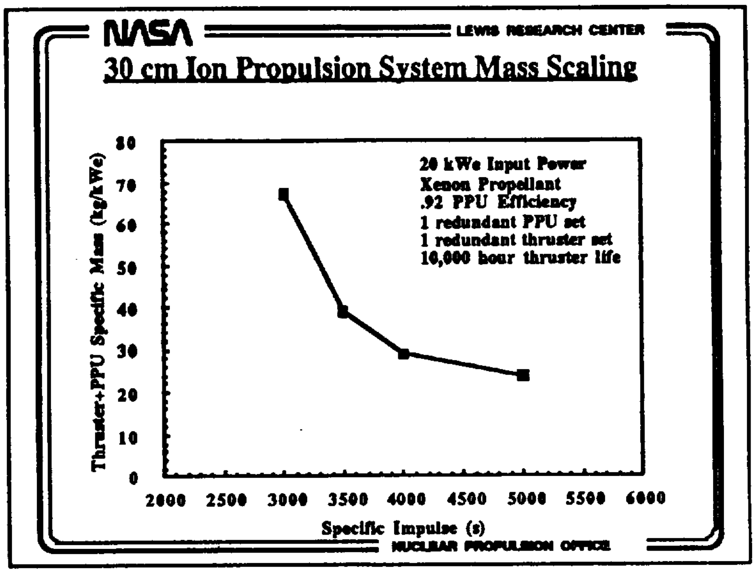
Radiator Area Scaling

Radiator area scaling is shown for the three options, with corresponding launch vehicle volumetric limits provided for reference. Volume limits are for the entire launch vehicle shroud, with no allowance for upper stage. The trade between Brayton and thermoelectrics is shown in the relative area for the two. The higher rejection temperature of the thermoelectrics allows a reduced radiator area. System specific masses are comparable, however, due to the higher efficiency of the Brayton power conversion. System and mission analysis will ultimately be based on three primary points: mission performance (specific mass), development time, and launch vehicle compatibility.



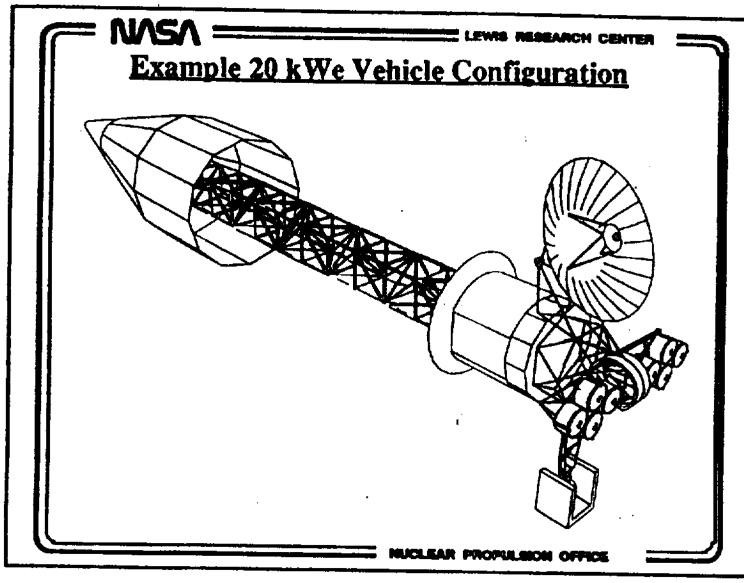
30 cm Ion Thruster Performance

Projected ion thruster performance is shown in terms of thrust efficiency and specific impulse. These data are necessary for trajectory and system optimization, in order to determine the proper design point in terms of thruster specific impulse and system power.



30 cm Ion Propulsion System Mass Scaling

The ion propulsion system includes thrusters, gimbals, power processors and associated thermal control. The above system is for a fixed input power to the power processor of 20 kWe. Specific mass decreases with specific impulse because of the decrease in the number of thrusters required to process the power. Included in the specific mass budget are an extra set of thrusters and power processors (PPU). The system is designed to last 30,000 hours, or almost 3.5 years. These data, in addition to specific masses for other lifetimes, have been provided to the mission analysts for more detailed trajectory analysis.



Example 20 kWe Vehicle Configuration

A conceptual design of a 20 kWe NEP vehicle configuration is shown above. Of key interest at this stage of the analysis is the design of the radiator and the location of the thrusters. These components have the potential for the greatest amount of interaction with the payload and launch vehicle. Overall vehicle integration will require detailed assessments of the configuration of these components. In addition, thruster location determines vehicle trajectory and steering capabilities. Placement of thrusters and their electronics will also impact transmission line designs. Currently, system designs assume that the thrusters are mounted as shown above, with the greatest distance between power processors and power conversion.

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CONCLUSION

- Low power NEP systems have been configured for initial mission studies
- Refined studies will be performed for detailed mission requirements, including packaging and development schedule
- Impact of system selection on NEP system evolution, near term performance will be assessed

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CONCLUSION

A range of low power NEP system performance parameters have been defined for initial scoping mission studies. Following the initial mission assessment, more refined studies will be developed. Included in these studies will be a development schedule and cost analysis for the system of interest, including the flight system. Trade studies of system options, such as the nominal versus scaled reactor options, will continue in parallel with mission analysis.