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Nuclear Electric Propulsion: An Integral Part of NASA's Nuclear Propulsion Project

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NUCLEAR PROPULSION PROJECT (NASA)

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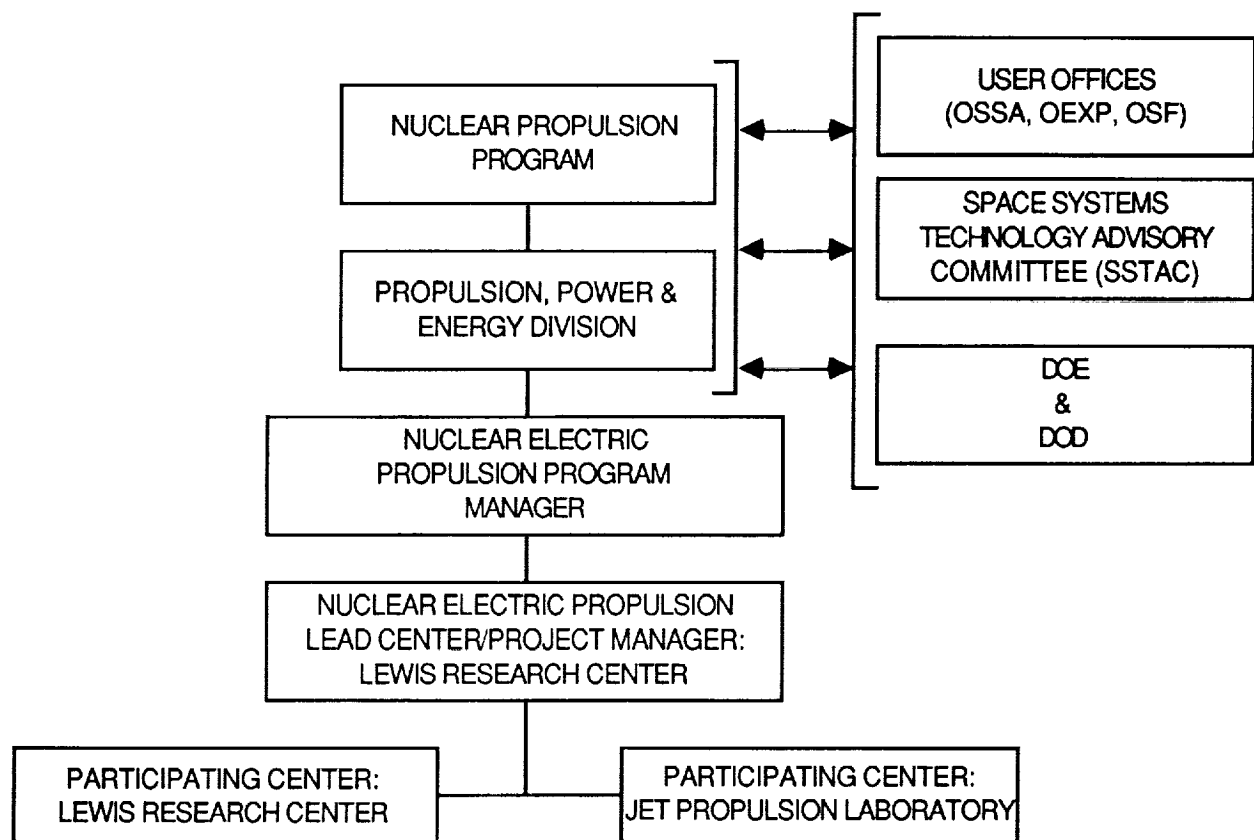


FIGURE 1. Nuclear Electric Propulsion Program Management Structure.

Interest in high power electric propulsion has been building for several years. The National Commission on Space (1986) advocated a number of challenging missions, such as a return to the Moon, unmanned and manned exploration of Mars and its moons, and unmanned scientific exploration of the rest of the solar system. Many of these missions would be enhanced, and some would be enabled by high I_{sp} electric propulsion. To perform the challenging future missions, high power and high I_{sp} systems will be required. Candidate thrusters include electrostatic (ion) and magnetoplasmadynamic (MPD) engines, with electrodeless approaches representing a longer term possibility. Electric propulsion is also applicable to advanced robotic exploration missions, offering both decreased propellant mass (and/or increased payload) and reduced trip times for deep space missions. There are also many potential applications for high I_{sp} electric propulsion at the tens of kilowatts available from large solar power systems. High I_{sp} clearly offers propellant mass savings, but in order to practically exploit that benefit for space missions, it is necessary for the overall vehicle to exhibit acceleration levels sufficient to meet mission time lines. This requirement necessitates low specific mass and high efficiency propulsion and power systems in order to keep power system mass low.

The planning of the NEP Program builds on the earlier Cargo Vehicle Propulsion Program Plan (Stone 1988) augmented substantially by a series of panel activities in support of the overall Nuclear Propulsion Project. These recent activities were initiated by workshops on NTP (Clark 1991) and NEP (Barnett 1991). These panels worked various planning issues and were coordinated through combined meetings and panel chairmen's meetings and were led by a DOE/DoD/NASA interagency steering group. Reports are being prepared by these panels, which were as follows:

- Nuclear Safety Policy Working Group,
- Mission Analysis Panel,
- NTP Technology Panel,
- NEP Technology Panel,
- Nuclear Fuels/Materials Panel, and
- Test Facilities Panel.

CURRENT PROJECT PLAN

The original Project Plan was prepared in Fiscal Year (FY) 1990 in parallel with Workshops on NEP and NTP (Barnett 1991 and Clark 1991, respectively) with the target of reaching Technology Readiness Level (TRL) of 6 (Table 1) for NTP and TRL-5 for NEP in 2006, in time to support the Space Exploration Initiative (SEI). The plan has been updated as a result of the panel activities described in the preceeding paragraph and a series of interagency and NASA intercenter meetings (Clark and Miller 1991 and Doherty 1991). Because of the slower than anticipated funding growth, the TRL targets for both NTP and NEP have been delayed to 2009.

TABLE 1. NASA Technology Maturation Milestones for Space Application.

Level	Description
<u>Technology Development</u>	
1.	Basic Principles Observed and Reported.
2.	Technology Concept/Application Formulated.
3.	Analytical and Experimental Critical Function and/or Characteristic Proof-of-Concept.
4.	Component and/or Breadboard Validation in Laboratory.
5.	Component and/or Breadboard Demonstrated in Relevant Environment.
6.	System Validation Model Demonstrated in Relevant/Simulated Environment.
7.	System Validation Model Demonstrated in Actual Environment.
<u>Advanced Development</u>	
8.	Technology Applied to Construction of Component and/or Breadboard of Expected Flight Hardware Configuration.
9.	Capability of Full Scale Subsystem Prototype Demonstrated in Ground Tests.
10.	Capability of Full Scale Subsystem Prototype Demonstrated in Actual Use.
<u>Flight Hardware Development</u>	
11.	Full Scale System Prototype.
12.	Capability Demonstrated in Flight Test of Flight Hardware.
13.	Capability Demonstrated by Operational Flight Experience.

The top level work breakdown structure (WBS) for the project is give in Table 2, which also includes more detail where work will be conducted in FY 1992. The planned work is described in more detail in the following paragraphs.

Project Management

The Nuclear Propulsion Project Office coordinates the activities in various LeRC technology organizations, at the Marshall Space Flight Center (MSFC) (NTP) and at JPL (NEP). Coordination and communication with DoD and DOE laboratories are also important in management, particularly with regard to the nuclear sub-systems tasks, which are performed by DOE. The Idaho Engineering Laboratory (INEL) has the lead in reactor systems, while the Los Alamos National Laboratory (LANL) has the lead in fuels development. This task also includes the development and implementation of a plan for informing the public of the rationale for SEI and the important role that nuclear propulsion will play in space exploration.

TABLE 2. Nuclear Propulsion Project Work Breakdown Structure (Elements Planned for First-Year Activity).

PROJECT MANAGEMENT
Project Management
Information Systems
CONCEPT DEVELOPMENT AND SYSTEMS ENGINEERING
System and Interface Requirements Definition
System Level Design/Trade Studies
Mission Analysis
Engine System Modeling and Analysis
INNOVATIVE TECHNOLOGIES
Studies/Modeling
Proof of Concept Tests
NEP TECHNOLOGY
Nuclear Sub-Systems
Fuels
Non-Nuclear Sub-Systems
Thrusters
Thermal management
Power management, distribution & processing
NTP TECHNOLOGY
Nuclear Sub-Systems
Fuels
Non-Nuclear Sub-Systems
Materials
Instrumentation and controls
Turbopumps
Nozzles
Structures
FACILITIES
Nuclear
Non-Nuclear
Space simulation vacuum chambers (NEP)
High temperature facility (NTP)
SAFETY, QUALITY ASSURANCE, RELIABILITY AND ENVIRONMENTAL ISSUES
Safety Planning and Integration
Safety Analyses
Reliability

Concept Development and System Engineering

This effort was initiated in FY 1991 for NTP in the areas of requirements definition and engine system modeling and analysis. These activities will be accelerated in FY 1992, and further design work will be initiated with significant industry participation. For NEP the effort will focus on system level design/trade studies. These NEP studies will identify combinations of reactor, power conversion, heat rejection and thruster systems which show significant enough promise in one or more of the mission categories to warrant subsequent conceptual design studies.

Innovative Technologies

High-risk/high-payoff technologies for performance enhancements beyond the 2009 target levels will be pursued on a paced basis. Efforts will be initiated with studies and modeling leading to proof of concept tests. For those technologies achieving successful proof of concept, conceptual designs will be developed and critical components designed and tested.

NEP Technology

Most of the fuels activity in the early phase of this program will be on NTP since near-term NEP fuels will probably be derived from the SP-100 Program. The thruster technology will be focused primarily on MPD initially since ion propulsion is funded by the NASA Low Thrust Technology Program. The MPD effort at LeRC and JPL will concentrate on increasing power level and efficiency while also advancing the theoretical understanding of electrode phenomena. Advanced heat pipe technologies will be addressed in the Thermal Management area, while high temperature electronics will be the first activity under Power Management, Distribution and Processing.

NTP Technology

The NTP technology developments by LeRC, MSFC and DOE may also benefit the NEP Program. Potential areas of synergy include fuels (at a basic level), instrumentation and controls (radiation-tolerant, high temperature), and health monitoring.

Facilities

Initial NTP facility activities will focus on high temperature hydrogen test capability. Early NEP facility activity will enhance existing capability of space simulation vacuum facilities by increasing the heat rejection and pumping capability resulting in increasing operating time at high power.

Safety and Environmental Issues

The initial activities in this area are largely common between NTP and NEP. Early activity will be primarily focused on planning and developing criteria appropriate for the ultimate piloted spacecraft application as well as ground testing issues. Preparation of Environmental Impact Statements will be initiated.

CURRENT STATUS

The NEP Program is underway at a significant pace, though not yet at a pace which assures our ability to meet the more aggressive proposed SEI timelines. The NEP effort is very much related to the ongoing SP-100 Program, but SP-100 currently addresses very general requirements, not specifically those of NEP. The status of advocacy for NEP is greatly improved over the recent past. NEP has often been proposed as enabling to many outer planetary missions, but received little serious attention or support from the space science community. Studies conducted in 1991 by JPL have done much to improve this situation and have aroused serious interest in the space science community (Yen 1991). Although Synthesis Group On America's Space Exploration Initiative (1991) selected NTP for piloted Mars missions, NEP was recommended for cargo applications. Recent LeRC studies (George, Hack and Dudzinski 1991) have shown that NEP may be quite competitive with NTP even for fast piloted missions to Mars.

CONCLUDING REMARKS

The Nuclear Electric Propulsion Program (NEP) is accelerating toward the capability to support robotic and human exploration of the solar system. Interagency and intercenter cooperation is enabling significant progress in spite of the fragmented funding for this program - from the CSTI High Capacity Power Program, SP-100, and NASA's Base Research and Technology Program. Potential users of this technology, in both the space science and human exploration communities are becoming increasingly aware of the enhancing and enabling capabilities of NEP.

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13. ABSTRACT (Maximum 200 words) The National Aeronautics and Space Administration (NASA) has initiated a technology program to establish the readiness of nuclear propulsion technology for the Space Exploration Initiative (SEI). This program was initiated in the past fiscal year with a very modest effort identified with nuclear thermal propulsion (NTP); however, nuclear electric propulsion (NEP) is also an integral part of this program and builds upon NASA's Base Research and Technology Program in power and electric propulsion as well as the SP-100 space nuclear power program. Although the Synthesis Group On America's Space Exploration Initiative has identified NEP only as an option for cargo missions, recent studies conducted by NASA Lewis show that NEP offers the potential for the early manned Mars missions as well. Lower power NEP is also of current interest for outer planetary robotic missions. This paper reviews current plans for the overall nuclear propulsion project, with emphasis on NEP and those elements of NTP program which have synergism with NEP.				
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