CONF-920107--23

WHC-SA-1402-FP

Nuclear Electric Propulsion Development and Qualification Facilities

Prepared for the U.S. Department of Energy
Assistant Secretary for Nuclear Energy

Westinghouse
Hanford Company Richland, Washington

Hanford Operations and Engineering Contractor for the
U.S. Department of Energy under Contract DE-AC06-87RL10930

DISTRIBUTION RESTRICTED TO U.S. ONLY

Approved for Public Release

WHC-SA--1402

DE92 004262

Nuclear Electric Propulsion Development and Qualification Facilities

D. S. Dutt
Westinghouse Hanford Company

K. Thomassen
Lawrence Livermore National Laboratory

J. Sovey
NASA Lewis Research Center

M. Fontana
Oak Ridge National Laboratory

Date Published
November 1991

To Be Presented at
Ninth Symposium on Space
Nuclear Power Systems
Albuquerque, New Mexico
January 12-16, 1992

Prepared for the U.S. Department of Energy
Assistant Secretary for Nuclear Energy

MASTER

Westinghouse Hanford Company P.O. Box 1970 Richland, Washington 99352

Hanford Operations and Engineering Contractor for the
U.S. Department of Energy under Contract DE-AC06-87RL10930

Log Nr. 189

NUCLEAR ELECTRIC PROPULSION DEVELOPMENT AND QUALIFICATION FACILITIES

Dale Dutt
Westinghouse Hanford Company
P. O. Box 1970
Richland, WA 99352
(509) 376-9336

Jim Sovey
NASA Lewis Research Center
2100 Brookpark Road
Cleveland, OH 44135
(216) 977-7454

Keith Thomassen
Lawrence Livermore National Laboratory
7000 East Avenue
Livermore, CA 94550
(415) 422-9815

Mario Fontana
Oak Ridge National Laboratory
P. O. Box 2009
Oak Ridge, TN 37831
(615) 574-0273

CAMERA READY MANUSCRIPT prepared for:

Ninth Symposium
on Space Nuclear Power Systems
Albuquerque, New Mexico
12-16 January 1992

initial submission:

final submission: 18 November 1991

Author to whom correspondence should be sent: Dale Dutt

NUCLEAR ELECTRIC PROPULSION DEVELOPMENT AND QUALIFICATION FACILITIES

Dale Dutt
Westinghouse Hanford Company
P. O. Box 1970
Richland, WA 99352
(509) 376-9336

Jim Sovey
NASA Lewis Research Center
2100 Brookpark Road
Cleveland, OH 44135
(216) 977-7454

Keith Thomassen
Lawrence Livermore National Laboratory
7000 East Avenue
Livermore, CA 94550
(415) 422-9815

Mario Fontana
Oak Ridge National Laboratory
P. O. Box 2009
Oak Ridge, TN 37831
(615) 574-0273

Abstract

This paper summarizes the findings of a Tri-Agency panel; consisting of members from the National Aeronautics and Space Administration (NASA), U.S. Department of Energy (DOE), and U.S. Department of Defense (DOD); charged with reviewing the status and availability of facilities to test components and subsystems for megawatt-class nuclear electric propulsion (NEP) systems. The facilities required to support development of NEP are available in NASA centers, DOE laboratories, and industry. However, several key facilities require significant and near-term modification in order to perform the testing required to meet a 2014 launch date. For the higher powered Mars cargo and piloted missions, the priority established for facility preparation is: (1 thruster developmental testing facility, (2 thruster lifetime testing facility, (3 dynamic energy conversion development and demonstration facility, and (4 advanced reactor testing facility (if required to demonstrate an advanced multiwatt power system). Facilities to support development of the power conditioning and heat rejection subsystems are available in industry, federal laboratories, and universities. In addition to the development facilities, a new preflight qualification and acceptance testing facility will be required to support the deployment of NEP systems for precursor, cargo, or piloted Mars missions. Because the deployment strategy for NEP involves early demonstration missions, the demonstration of the SP-100 power system is needed by the early 2000s.

INTRODUCTION

The President's initiative to return humans to the surface of the moon and then to proceed with human exploration of Mars requires high performance propulsion systems for cargo and human transport. Nuclear electric propulsion (NEP) and nuclear thermal propulsion (NTP) have been identified as enabling technologies to support the Mars piloted mission. Six panels with members from the U.S. Department of Energy (DOE), National Aeronautics and Space Administration (NASA), and the U.S. Department of Defense (DOD) were formed to review technology status and formulate plans for nuclear propulsion development for a piloted mission to Mars in the 2014 to 2019 timeframe.

Re-establishment of the facilities required for development and to conduct performance testing will be one of the pacing activities for the NP Program. Thus, a panel was formed to review testing requirements, resulting facility requirements, available facilities, and, then, recommend a facilities strategy for the participating agencies. This panel formed two subpanels to review the facility needs and availability, and funding priority for NEP and NTP, respectively. The activities of the NEP Facilities Panel are summarized in the remainder of this paper.

PROCESS

The Nuclear Electric Propulsion Facilities Panel and the Nuclear Electric Propulsion Technology Panel have common members and often meet jointly to ensure the responsiveness of planning. The development/demonstration strategy which is advocated by the NEP Technology Panel is key to the facilities plan. NEP systems are comprised of five major subsystems, heat source (reactor), energy conversion, power conditioning, heat rejection, and thrusters (Figure 1). These subsystems are relatively independent and can be developed and lifetime or performance demonstrated at the subsystem level. Testing requirements for NEP technologies, components, and subsystems, were provided by the NEP Technologies and the Fuels and Materials Panels (Table 1).

TABLE 1. Technology Requirements

Subsystem	Interplanetary Precursor 100 kWe, 30-50 kg/kWe	Lunar/Mars Cargo 1-5 MWe, 10-20 kg/kWe	Mars Piloted: 500-600 Day 10-20 MWe, 7-10 kg/kWe	Mars Piloted: Quick Trip 10-40 MWe, 3-7 kg/kWe
Reactor	SP-100 to Technology Readiness Level (TRL)-5, 1996	SP-100 Growth or Advanced, 25 MWt, 2000	Multiple Units	Advanced Reactor System, TRL-05, 2006
Power Conversion	Thermal Electric, TRL-5, 1997	Dynamic, TRL-5, 2000	Light-Weight Dynamic, TRL-5, 2006	Upgrade, TRL-5, 2006
Radiator-Heat Rejection	Pumped Loop to TE/Heat Pipe Radiator, TRL-5, 1997	Heat Pipe Carbon-Carbon, TRL-5, 2000	Upgrade, TRL-5, 2006	Upgrade, TRL-5, 2006
Power Management and Distribution (PMAD)	Shielded from Radiation, Conventional Si Technology, TRL-5, 1998	Shielded Conventional, TRL-5, 2000	High Temperature, Advanced, TRL-5, 2006	Upgrade, TRL-5, 2006
Thruster	Magnetoplasmadynamic (MPD) or Ion Thruster, TRL-5, 1998, Because of Lifetime Test	MPD or Ion, TRL-5, 2000	MPD, Ion or Advanced, TRL-5, 2006	Upgrade, TRL-5, 2006

One of the major assumptions/agreements reached by the NEP Technology and Facilities Panels was that an integrated NEP system test cannot be properly performed on earth. The first test of the entire propulsion system will probably be conducted in space on a demonstration mission. Thus, NEP lends itself to an evolutionary developmental approach where initial precursor missions, such as interplanetary science probes, are conducted with relatively near-term technologies as demonstration tests. Later, higher power cargo and piloted missions will use NEP systems comprised of larger scale subsystems or advanced technologies.

The modularity/independence of NEP subsystems greatly reduced the demand on any individual facility. Most of the NEP subsystems have scalability issues that must be addressed by a rigorous testing program. Thus, all of the recommended facilities are sized to accommodate those components/subsystems needed for the higher power piloted Mars missions. Subsystem integration tests for the reactor/conversion and thruster/power conditioning will be accommodated in the proposed facilities.

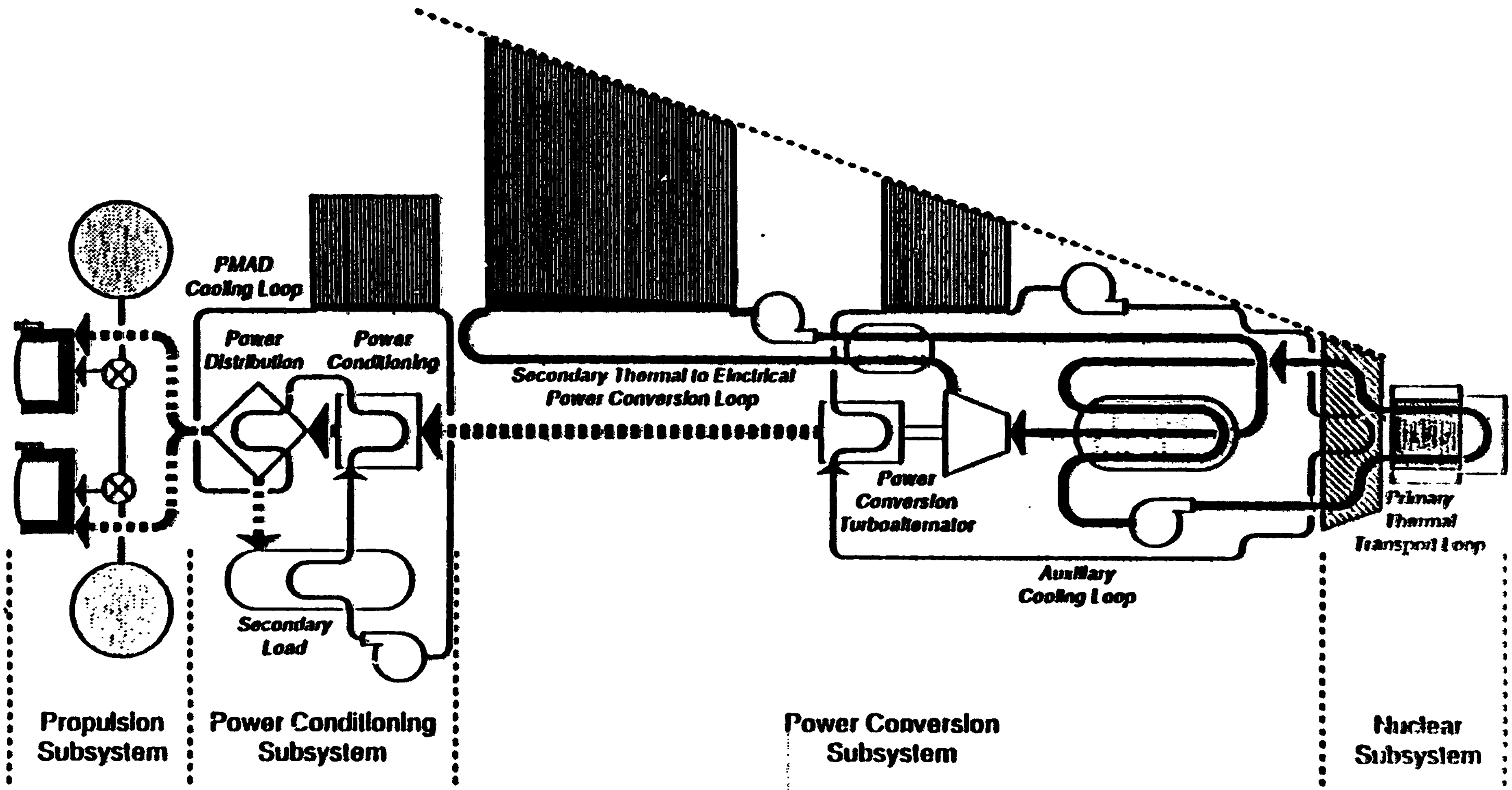

FIGURE 1. Nuclear Electric Propulsion System Schematic (from Doherty, 1991).

OVERVIEW OF AVAILABLE FACILITIES

The facility requirements to meet the testing requirements are provided in Table 2.

TABLE 2. Major Facility Requirements.

	Near Term	Cargo	Piloted A	Piloted B
Reactor	X	50 MWt ——————→		
Power Conversion	X	2.5 MWe ——→		5 MWe
Heat Rejection	X	*	*	*
PMAD	*	*	*	*
Thruster	< 0.5 MWe Component and Lifetime Testing (2 Facilities)	~ 2 MWe ——————→ Upgrade for Systems Tests		

* - No new facility required, available in industry or laboratories.
X - Test facilities supplied by SP-100 Program.

Facilities to Support Reactor Development

The SP-100 Flight System Qualification Program is focused on demonstrating technology and components for a 100 kWe power system with thermoelectric conversions. Resolution of the issues of SP-100 technology scalability and (assuming the technology scales), the applicability of the currently planned SP-100 ground test to the larger, higher powered systems required for 5-40 MWe piloted mission is key to the final facilities plan for reactor development.

In the event an advanced reactor technology is shown to provide significant mission performance benefits, an advanced fuels and materials technology program could be accommodated in existing DOE reactors. If the advanced concept is a liquid-metal-cooled fast reactor, the Fast Flux Test Facility and the Experimental Breeder Reactor-II can accommodate all planned testing. If the concept uses a gas-cooled Brayton cycle, a gas loop could be built for the Advanced Test Reactor.

The decision to conduct a large scale test (either with SP-100 or advanced technologies) would require an immediate commitment to develop a test facility to meet environmental, safety, and health requirements. The personnel at the SP-100 Test Site at Hanford provided cost and schedule estimates for modification of the facility to accommodate an order of magnitude increased thermal power (25 MWt). The 8- to 10-year construction schedule was accepted as typical for all potential reactor test sites. In addition to the Hanford Site, detailed reviews were conducted of the Idaho National Engineering Laboratory (INEL) Contained Test Facility, the Oak Ridge National Laboratory (ORNL) Experimental Gas Cooled Reactor, and the Sandia National Laboratories. Because of the perceived requirement for containment and remote locating, future and more detailed site reviews will focus on INEL, ORNL, and Hanford.

Facilities to Support Energy Conversion Development

The energy conversion technology used for the piloted Mars mission will most likely be a dynamic system (Brayton, Rankine, or Stirling). NASA and DOE laboratories have been active in energy conversion technology development since the 1960s. Historically, Brayton and Stirling conversion has been developed under the direction of NASA centers and Rankine under the direction of a DOE center.

A high temperature gas loop to support Brayton at ORNL was reviewed extensively, and NASA-Lewis has an ongoing Brayton development program. Brayton testing can be conducted by NASA and ORNL with minor upgrading of existing capabilities. If a full-scale Brayton development program were undertaken, it is likely that both the NASA and ORNL facilities would be used. The ORNL-led activities to demonstrate potassium Rankine in the 1960s and early 1970s provided a technology base. However, none of the facilities required for development of boilers, turbines, and subsystem testing exist today. A significant program would be required to re-establish those facilities, potentially by adapting liquid metal systems now on standby. System studies to determine if these facilities should be re-established are key to the NEP deployment schedule.

Facilities to Support Power Management and Distribution

Facilities for testing power conditioning and power management components and subsystems exist in university, industry, and government laboratories. No additional resource needs were identified by the panel.

Facilities to Support Thruster Development

Ion, magnetoplasmadynamic, and advanced thrusters issues are performance, lifetime, and scalability. There is a need for two test facilities; one for component development testing and a second for long term lifetime and performance testing. The key parameters for thruster testing facilities is the vacuum chamber size required for the megawatt-class thrusters.

Facilities at NASA-Lewis, Lawrence Livermore National Laboratory (LLNL), Oak Ridge National Laboratory, Arnold Engineering Development Center, Los Alamos National Laboratory, and Phillips Laboratories were reviewed for applicability. All the facilities reviewed will require some modification to accommodate the beam dump and achieve appropriate vacuum levels. Because of availability considerations, the facilities at NASA-Lewis, ORNL, and LLNL appear to be the most promising candidates (Sovey, 1991).

NASA-Lewis Research Center's Electric Power Laboratory houses two large space simulation chambers, tanks 5 and 6. Tank 5 is 4.6 m in diameter and 19 m long. Sufficient liquid helium or gaseous helium exists for 8-hour tests. Tank 6 is 7.6 m in diameter and 22 m in length. A NASA-funded rehabilitation of the tank is scheduled to be completed in January 1993. The tank will be capable of dissipating 0.35 MWe. The LLNL Magnetic Fusion Tandem Mirror Test Facility (MFTF) is 10.6 m in diameter and 55 m long. Large amounts of liquid helium storage capability, as well as 8 kW and 3 kW refrigeration/liquefier systems, are available onsite. Large magnets from the original program must be removed to allow use as a thruster test facility. The Large Coil Test Facility (LCTF) at ORNL is a 10.7-m-diameter, 9.1-m-high cylindrical chamber with a removable lid, vacuum capability, and liquid helium wall cooling; however, the helium cryosystems were last operated in 1986.

Facilities to Support Heat Rejection Development

A large number of vacuum chambers of appropriate size exist within industry, particularly aerospace companies. Although some additional heat rejection capability may be required, the anticipated costs are within the capability of a typical development program.

RECOMMENDATIONS

The subpanel recommendations are as follows:

1. Complete the SP-100 ground test and demonstration of thermoelectric conversion before the turn of the century to support flight demonstration and precursor missions;

2. Immediately start modifications to provide a thruster development test facility;

3. Immediately start modifications to provide a thruster lifetime test facility;

4. Complete system studies to determine the nee' for an advanced reactor system versus a scaled SP-100 reactor (the need for a new reactor test facili dependent on results); and

5. Initiate the construction of a dynamic conversion test facility based on results of the systems in item 4.

The thruster, power conversion, and advanced reactor development facilities are highest priority (Table 3). The facility requirements to develop NEP appears to be manageable within current budget expectations.

TABLE 3. Priority and Availability of the Facilities to Support NEP.

New/Modification	NEP Facility Funding Priority	Existing Facilities
	HIGHEST	
Thruster Component Development		Near-Term Fuels Fabrication
Thruster Lifetime		Near-Term Reactor Ground Test
Dynamic Energy Conversion		Heat Rejection
Advanced Reactor Ground Test[a]		PMAD
		Fuels & Materials Examination
		Unirradiated Fuels & Materials Testing
	MEDIUM	
Advanced Fuel Fabrication		Materials Irradiation Testing
Fuel Element Testing Loops		Safety and Off-Normal Operations
Flight Test Support		
	LOWEST	
Advanced Thruster (Particles) Testing		Control Systems
		Shielding

[a]If reactor > 50 MWt is needed, depends upon mission analysis/choices.

Acknowledgments

The contribution of the following NEP Facilities Panel members Sam Bhattacharyya (ANL), John Dearien (INEL), Bob Holcomb (ORNL), and Mike Mahaffey (WHC), and the Air Force's Phillips Laboratories and Arnold Engineering Development Center provided valuable guidance and technical balance to the facilities panel.

References

Sovey, J. S. et al., (1991), Test Facilities for the High Power Electric Propulsion, AIAA 91-3499, American Institute of Aeronautics and Astronautics, September 1991.

Doherty, M. P., (1991), Blazing the Trailway: Nuclear Electric Propulsion and Its Technology Program Plans, AIAA 91-3441, American Institute of Aeronautics and Astronautics, September 1991.

DISTRIBUTION

Number of copies

ONSITE

5	U.S. Department of Energy-Richland Operations Office	
	C. R. Richins (5)	A6-55
3	Westinghouse Hanford Company	
	Information Release Administration (2)	L8-07
	Document Processing and Distribution	L8-15