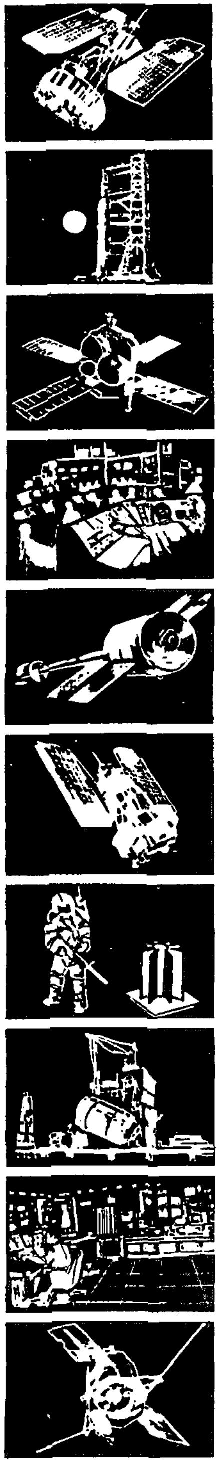
N72-26530

GE-NSP DOCUMENT NO. GESP-7074

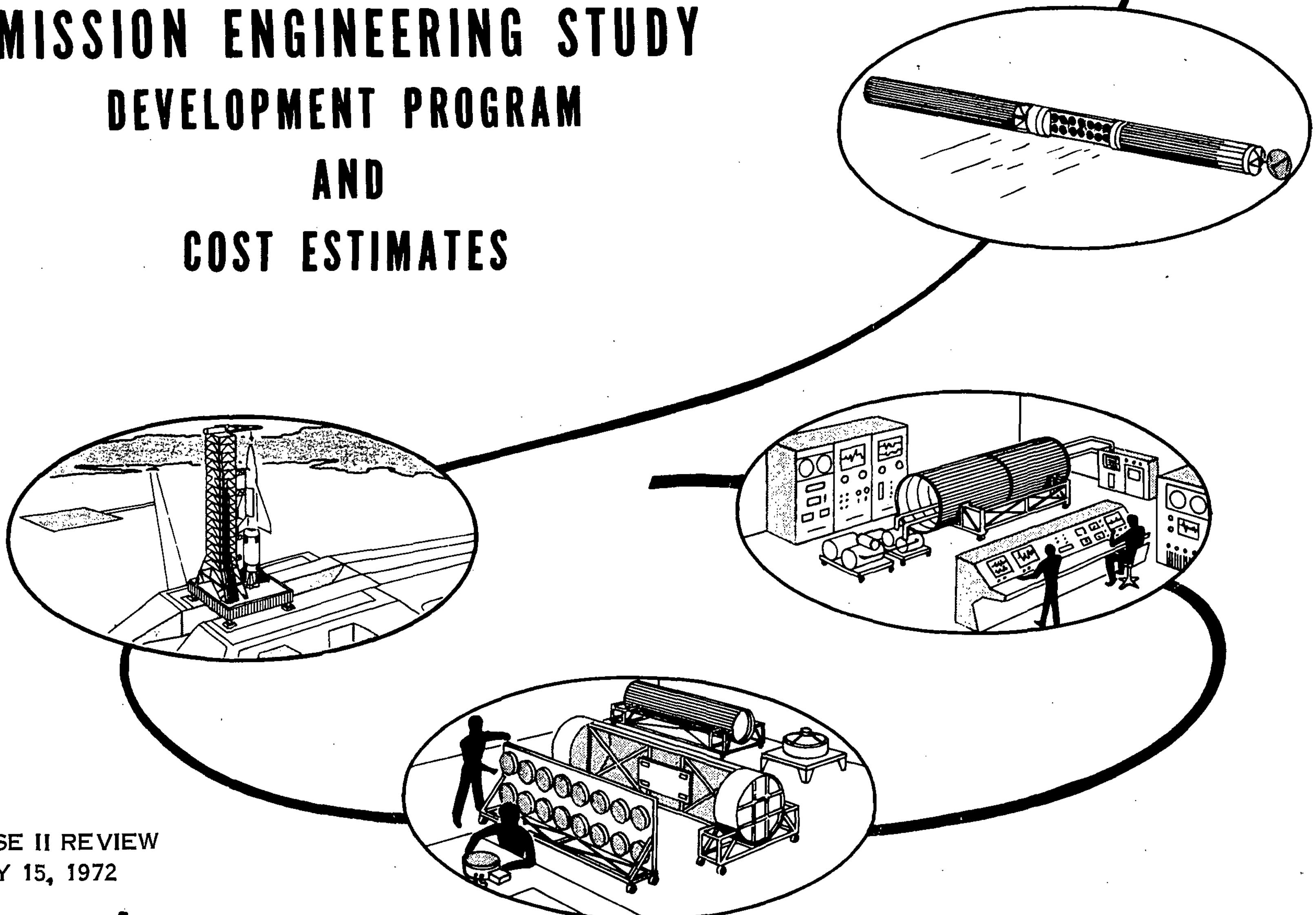
CASE FILE COPY

SPACE DIVISION



NUCLEAR ELECTRIC PROPULSION MISSION ENGINEERING STUDY

DEVELOPMENT PROGRAM AND COST ESTIMATES



PHASE II REVIEW
MAY 15, 1972

jpl

GENERAL ELECTRIC

THIS REPORT CONTAINS INFORMATION PREPARED BY THE GENERAL ELECTRIC COMPANY UNDER JPL SUBCONTRACT. ITS CONTENT IS NOT NECESSARILY ENDORSED BY THE JET PROPULSION LABORATORY, CALIFORNIA INSTITUTE OF TECHNOLOGY, OR THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION.

CONTRACT JPL 953104
GE-NSP DOCUMENT NO. GESP-7074

NUCLEAR ELECTRIC PROPULSION MISSION ENGINEERING STUDY
DEVELOPMENT PROGRAM AND COST ESTIMATES

PHASE II REVIEW
MAY 15, 1972

PREPARED FOR

THERMIONIC REACTOR SYSTEMS PROJECT
PROPULSION RESEARCH AND ADVANCED CONCEPTS SECTION

JET PROPULSION LABORATORY
4800 OAK GROVE DRIVE
PASADENA, CALIFORNIA, 91103

NUCLEAR SYSTEMS PROGRAMS
SPACE SYSTEMS ORGANIZATION
Valley Forge Space Center
P. O. Box 8661 • Philadelphia, Penna. 19101
GENERAL ELECTRIC

The purpose of this briefing is to present the results of the second six-month performance period of the Nuclear Electric Propulsion Mission Engineering Study.

The first part of the presentation consists of a brief overview of the program, identifying the study objectives and approach, and a discussion of the program status and schedule.

The program results completed in Phase II are reviewed and key conclusions to date are summarized. Planned effort for the remainder of the program is reviewed.

AGENDA

- PROGRAM OVERVIEW
  - BACKGROUND
  - OBJECTIVES
  - KEY GUIDELINES AND CONSTRAINTS
  - APPROACH
  - SCHEDULE AND STATUS SUMMARY
- PROGRAM RESULTS
  - DEVELOPMENT COSTS
    - COMMON GUIDELINES
    - BASELINE PROGRAM
    - MINIMUM PROGRAM
  - RECURRING COSTS
    - LIQUID METAL HEAT REJECTION SUBSYSTEM
    - FLIGHT NEP SYSTEM ESTIMATES
  - MISSION OPERATIONS
    - NEP SYSTEM STARTUP
    - COMMUNICATIONS
- CONCLUSIONS - PHASE II
- PLANNED FUTURE EFFORT - PHASE III

The study was awarded by NASA/JPL on April 12, 1971, and is scheduled for completion eighteen months later. A key point-of-departure for this effort is the thermionic spacecraft design studies completed for NASA/JPL under Contract JPL 952381. This effort provides the definition of the baseline nuclear thermionic spacecraft for comet rendezvous and outer planet exploration missions.

BACKGROUND

• CONTRACTING AGENCY	NASA/JPL
• CONTRACT VALUE	$158K
• START DATE	APRIL 12, 1971
• PERFORMANCE PERIOD	18 MONTHS
• JPL TECHNICAL MONITOR	DR. C.D. SAWYER
• GE PROGRAM MANAGER	W.Z. PRICKETT
• RECENT RELATED STUDIES	THERMIONIC SPACECRAFT DESIGN STUDY - CONTRACT JPL-952381

The overall study objectives are to perform a mission engineering study of nuclear electric spacecraft for unmanned outer planet missions to determine the implications of nuclear reactor power on future space science programs. In particular this effort will assist in providing the definition of a Nuclear Electric Propulsion (NEP) spacecraft with multi-mission capability, its development program and costs, and the impact of the availability of an NEP system on the space program.

STUDY OBJECTIVES

- INVESTIGATE AND DEFINE ALL OPERATIONAL ASPECTS OF A THERMIONIC NUCLEAR ELECTRIC PROPULSION SPACECRAFT
- DEFINE MISSION AND SPACECRAFT INTERACTIONS WITH THE EARTH LAUNCH VEHICLE, FACILITIES AND RELATED EQUIPMENT
- DEFINE GROSS PROPULSION SYSTEM DEVELOPMENT PROGRAM
- DEFINE IMPACT OF NUCLEAR ELECTRIC PROPULSION ON SPACE PROGRAM AND TECHNOLOGY REQUIREMENTS

PROVIDES:

- DESIGN GUIDELINES AND RECOMMENDATIONS LEADING TO A NEP SPACECRAFT WITH MULTI-MISSION CAPABILITY
- DEVELOPMENT SCHEDULE AND COSTS
- GSE REQUIREMENTS
- PACING TECHNOLOGY AREAS

The study makes maximum use of previous efforts in the areas of mission analysis and NEP spacecraft design. The Shuttle-Centaur DIT is the reference launch vehicle. The NEP spacecraft will employ high thrust earth escape and low thrust electric propulsion for trajectory termination. Emphasis is placed on multi-mission capability from a spacecraft design based on current or near term technology to maximize cost effectiveness and minimize propulsion system development costs.

KEY GUIDELINES AND CONSTRAINTS

- SHUTTLE - CENTAUR DIT IS BASELINE LAUNCH VEHICLE
- MAXIMUM USE OF PREVIOUS TRAJECTORY ANALYSIS
- MAXIMUM USE OF PREVIOUS PROPULSION SYSTEM DESIGN STUDIES
- HIGH THRUST (CHEMICAL) EARTH ESCAPE FOLLOWED BY ELECTRIC PROPULSION
- LOW THRUST ELECTRIC PROPULSION FOR TRAJECTORY TERMINATION
- COMET HALLEY RENDEZVOUS AND ONE OUTER PLANET MISSION
- EMPHASIS ON IMPACT OF NUCLEAR ELECTRIC PROPULSION ON MISSION OPERATIONS
- EMPLOY REALISTIC LEVEL OF TECHNOLOGY

The figure presents the six program tasks and their general interrelation. Task 1, Program Management, provides overall technical and financial control for the total program.

Task 2, Mission and Operational Studies, provides for mission analysis, comparison and selection of at least two missions for which the multi-mission NEP spacecraft will be designed. The mission analysis effort interfaces closely with trajectory analysis performed by the Jet Propulsion Laboratory and NASA-Ames. The propulsion system specific weights, a key parameter in the mission analysis, are based on the NEP spacecraft designs developed for JPL under contract 952381.

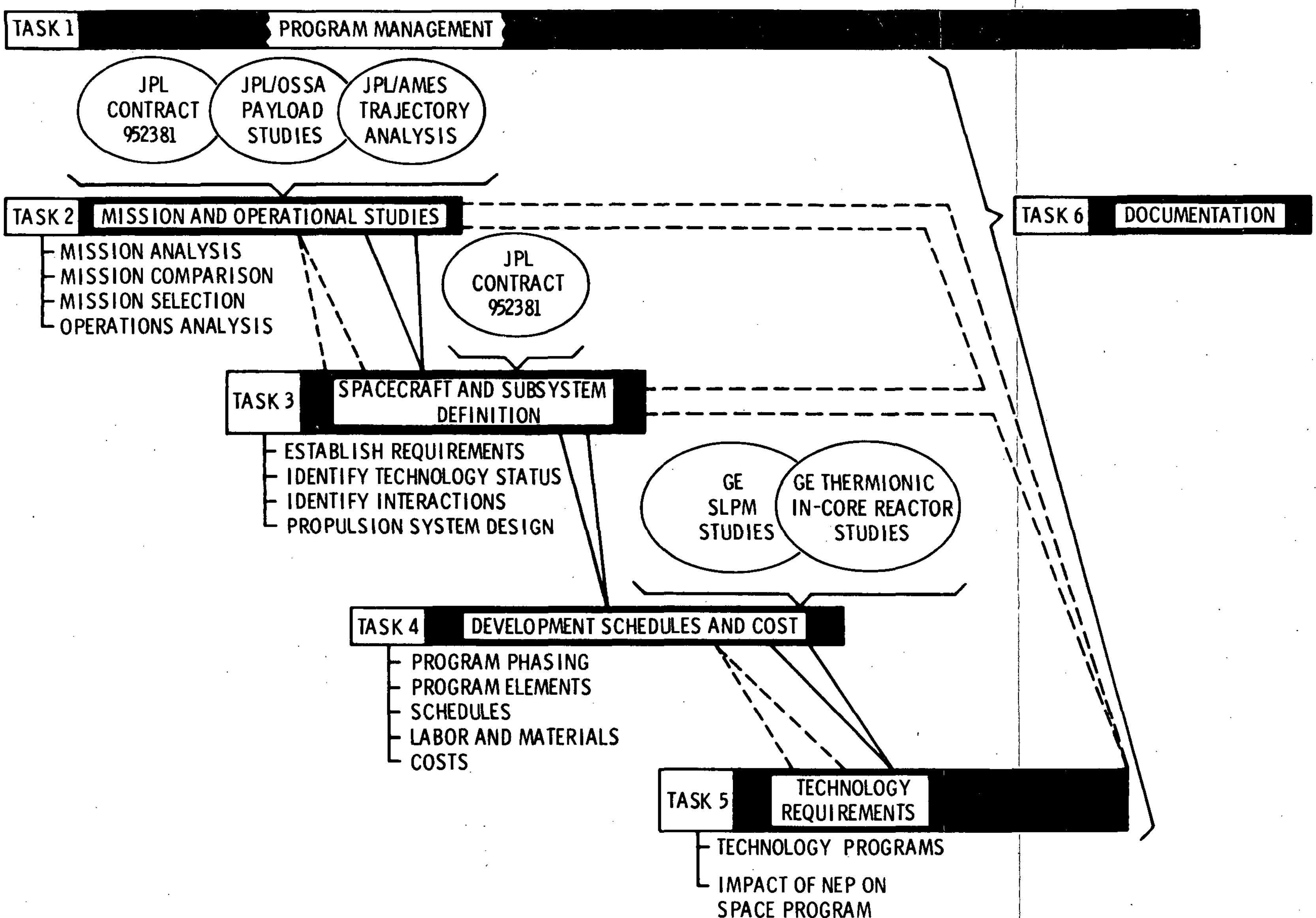
The mission operations definition is also accomplished under Task 2. This effort defines the sequence of events associated with the application of the NEP spacecraft, beginning with propulsion system fabrication, continuing through the pre-launch, launch, near-earth-orbit and heliocentric mission phases, and culminating with the arrival or terminal mission phase.

Task 3 provides for the preliminary design definition of the multi-mission NEP spacecraft. Design requirements are based on the Task 2 results to assure applicability to comet rendezvous and multiple outer planet missions. The preliminary design will be supported by work previously accomplished under JPL contract 952381.

Propulsion system development schedules and costs are defined under Task 4. The scope of this effort will include definition of program phasing, program elements, schedules, labor hours and type, materials and costs.

Key technology development requirements are particularized within Task 5, which also provides an assessment of the impact that the availability of a NEP spacecraft would have on the space program. Documentation is accomplished under Task 6.

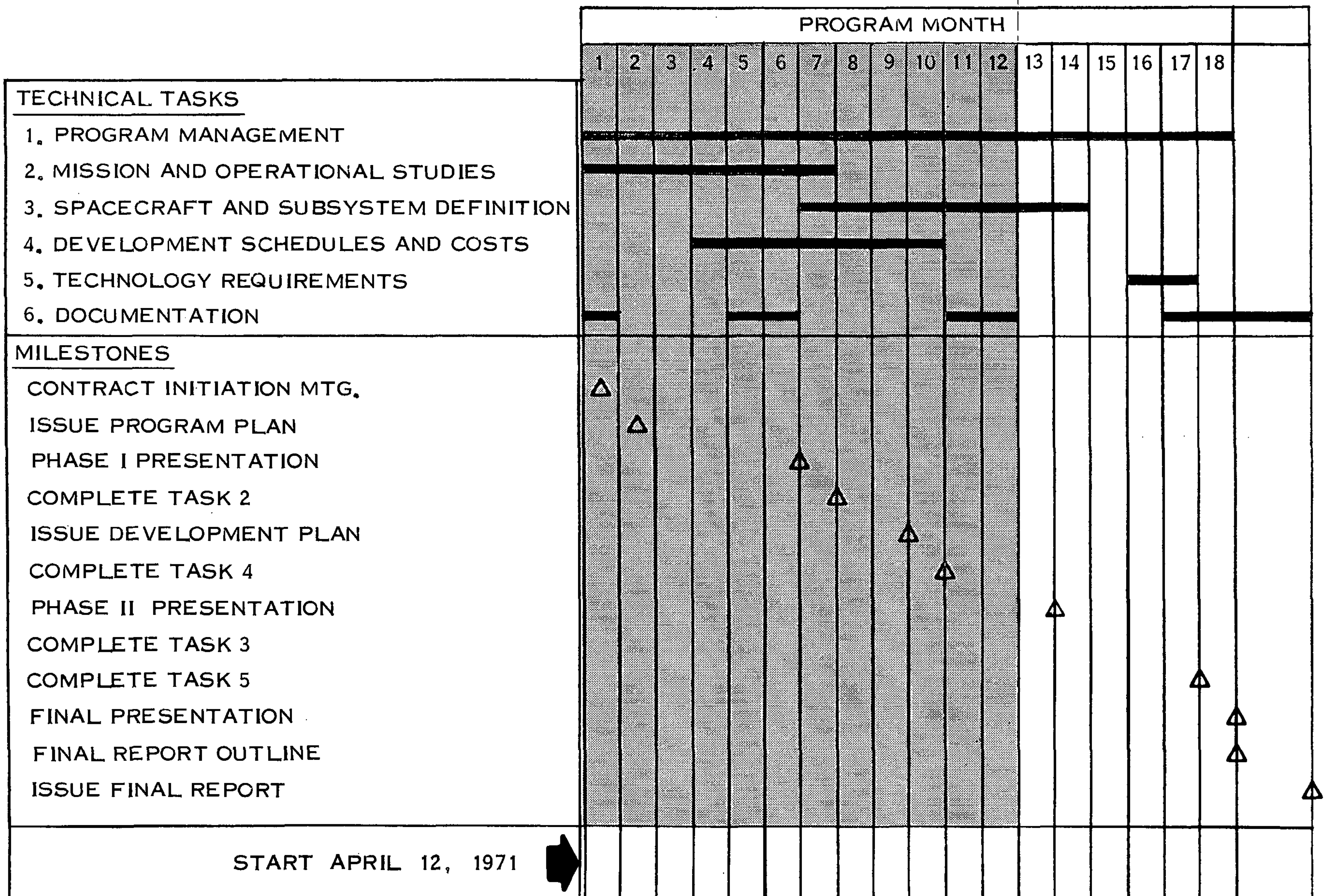
STUDY APPROACH



This performance review summarizes the second six months of the study. The mission analysis effort has been completed with the selection of the Comet Halley rendezvous mission and a tight Jupiter orbiter as the reference missions. The mission operations definition has been completed, together with a preliminary assessment of their impact on the multi-mission NEP spacecraft design and arrangement. Effort has been completed in the areas of power subsystem start-up and communications. Work on the propulsion system development program and costs has been completed. Work on the multi-mission NEP system has been initiated.

SPACE DIVISION

PROGRAM SCHEDULE



The second part of the briefing presents the details of the work being performed and the significant results of this reporting period.

AGENDA

- PROGRAM OVERVIEW
  - BACKGROUND
  - OBJECTIVES
  - KEY GUIDELINES AND CONSTRAINTS
  - APPROACH
  - SCHEDULE AND STATUS SUMMARY
- PROGRAM RESULTS
  - DEVELOPMENT COSTS
    - COMMON GUIDELINES
    - BASELINE PROGRAM
    - MINIMUM PROGRAM
  - RECURRING COSTS
    - LIQUID METAL HEAT REJECTION SUBSYSTEM
    - FLIGHT NEP SYSTEM ESTIMATES
  - MISSION OPERATIONS
    - NEP SYSTEM STARTUP
    - COMMUNICATIONS
- CONCLUSIONS - PHASE II
- PLANNED FUTURE EFFORT - PHASE III

The main effort during Phase II of the program has been directed toward the definition of NEP system development costs. Alternate development schedules have been examined which illustrate the cost impact of alternate levels of technology, system prototype and/or complete NEP system ground tests. Extensive system and subsystem prototype tests do not appear to be required to assure a reasonably high probability of mission success. Because of the inherent reliability of the thermionic NEP system, combined nuclear system tests are not necessary in the development program, although such tests have been considered and their cost evaluated. Program options presented all provide high visibility of major program cost elements.

The NEP power system liquid metal heat rejection component production costs, over and above their development costs through the flight unit, have been assessed under a separate study, and are reported here.

SPACE DIVISION

OBJECTIVES
DEVELOPMENT PROGRAM

- PROVIDE GROSS PROPULSION SYSTEM DEVELOPMENT SCHEDULE AND COSTS

- PROVIDE VISIBILITY OF PROGRAM COST ELEMENTS

- DEFINE MAN HOURS AND LABOR TYPES

- ESTIMATE LIQUID METAL HEAT REJECTION COMPONENT PRODUCTION COSTS

A 120 kWe NEP system employing an internal fuel reactor, assumed to deliver 40 VDC, is employed as the baseline size system for this NEP system development cost estimate. This side thrust nuclear electric propulsion system has been described in Phase I of this study, and has been the subject of earlier comprehensive design studies. The system operating life objective is of the order of 50,000 hours, with 10,000 hours to 20,000 hours full power capability for the power system.

Stainless steel is assumed for the power system liquid metal containment. The main radiator is assumed to be Cu-SS tube and fin, although the cost impact of beryllium-stainless radiators has been assessed. The NEP system structure is assumed to be aluminum or stainless steel, depending on the temperature level.

SPACE DIVISION

KEY GUIDELINES AND ASSUMPTIONS NUCLEAR ELECTRIC PROPULSION SYSTEM

- 120 kWe TO THRUST SUBSYSTEM
- 40 VDC INTERNAL FUEL REACTOR
- STAINLESS STEEL LIQUID METAL CONTAINMENT
- SIDE THRUST SPACECRAFT
- Cu-SS RADIATORS
- STAINLESS STEEL AND ALUMINUM STRUCTURE
- REDUNDANT LIQUID METAL RADIATOR - FOUR INDEPENDENT LOOPS

The baseline development program employs tests to demonstrate technology readiness of key components such as thermionic fuel elements. Liquid metal heat rejection loop components are considered relatively state-of-the-art because of extensive development completed in this area by Atomic International for the AEC and General Electric for NASA. However, limited component development is planned for this particular application. The solar electric program is assumed to provide the basic thrust system ion engine and power conditioning technology. Partial and limited full ion engine array tests are scheduled to verify the application of this technology to the NEP system.

The baseline program employs system operational tests to verify the performance of major NEP systems. These include the thermionic reactor, the main heat rejection system employing one-quarter to one-third of the full size radiator, and the ion engine array with its associated power conditioning.

The type acceptance tests for the flight NEP system employs a complete spacecraft, except that the reactor mechanical (mass) and electrical characteristics are simulated.

SPACE DIVISION

KEY GUIDELINES AND ASSUMPTIONS
DEVELOPMENT APPROACH

- DEMONSTRATE TECHNOLOGY READINESS BY COMPONENT TESTS
  - THERMIONIC FUEL ELEMENTS
  - EM PUMP
  - ION ENGINES

- SYSTEM OPERATIONAL TESTS
  - GROUND PROTOTYPE REACTOR
  - LIQUID METAL HEAT REJECTION (QUARTER RADIATOR)
  - ION ENGINE ARRAY/POWER CONDITIONING

- FLIGHT HARDWARE TYPE ACCEPTANCE (TA) NEP SYSTEM (DUMMY REACTOR)

All development program options evaluated assume that completion includes the design, fabrication and launch of one NEP system. All basic ground support equipment and facility costs identified are included. NEP system component development and flight system cost data have been obtained from NASA/JPL, the AEC, and their contractors where necessary.

All costs assume FY 1972 dollars. No escalation and no contingency costs are included. Four manpower classes are employed where applicable: engineering, drafting, technician and hourly. Assumed overhead is 120 percent of labor dollars. General and Administrative costs are assumed at 10 percent of total labor overhead and materials.

No fee is included in the costs presented. This will amount to 5 percent to 10 percent of the program total, depending on the contracting structure and the number of subcontractors employed.

No allowance is included for government agency monitoring and other participation. This could add an additional 8 percent to 10 percent to the total program cost. Alternately, performance of key program elements by government laboratories and agencies would act to reduce total program costs.

COMMON KEY GUIDELINES AND ASSUMPTIONS SCHEDULES AND COSTS

- BUILD ONE FLIGHT NEP SYSTEM
- ESTIMATED GSE AND FACILITY COSTS
- REACTOR COSTS BASED ON GULF GENERAL ATOMIC DATA
- ION ENGINE COSTS BASED ON JET PROPULSION LABORATORY DATA
- SHIELD COSTS PER ATOMICS INTERNATIONAL DATA
- FISCAL 1972 DOLLARS
- FOUR MANPOWER CLASSES:

ENGINEERING	@ \$11.00/HOUR
DRAFTING	@ \$ 7.00/HOUR
TECHNICIAN	@ \$ 8.00/HOUR
HOURLY	@ \$ 5.00/HOUR

- OVERHEAD AT 120 PERCENT OF TOTAL LABOR
- GENERAL AND ADMINISTRATIVE COSTS AT 10 PERCENT LOM
- NO FEE INCLUDED IN COSTS SHOWN

Stainless steel or aluminum structure is assumed for the NEP system. The selection between the two depends upon the temperature level of the system where structure is required. The impact on NEP system costs of extensive use of beryllium structure is assessed. An extensive structural development program is required for the NEP system, independent of the program option evaluated. This includes dynamic and thermal mockups and tests, an engineering development mockup, and an electrical harness mockup. Costs are included for the adapter structure required to attach the NEP system to the Centaur kick stage. (The NEP System - Centaur package is launched to earth orbit by the Shuttle. The Centaur stage then launches the NEP system to earth escape.)

Complete tooling costs are included as a part of the GSE. Development of the propellant tank, which also functions as the main gamma shielding, is assumed to be required for all NEP System development program options evaluated. It is doubtful that this technology can be taken directly from the SEP program, because of the unique geometry and nuclear radiation environment operation required for the NEP System.

No shielding, or non-nuclear instrumentation and control, technology development requirements are identified.

Flight Nuclear safety and other safety costs are organized in the Program Management and Systems Engineering tasks. However, total safety costs are often quoted separately for fiscal visibility. No reactor destructive nuclear safety test costs are included, although their costs are estimated.

Identified Launch and Mission Operations costs are limited to contractor support, and are identical for all three programs evaluated. No launch vehicle costs are included in the program total costs, although their costs are estimated.

SPACE DIVISION

COMMON KEY GUIDELINES AND ASSUMPTIONS SCHEDULES AND COSTS (CONTINUED)

- STAINLESS/ALUMINUM STRUCTURE
- COMPLETE STRUCTURAL DEVELOPMENT HARDWARE
  - DYNAMIC MOCKUP
  - THERMAL MOCKUP
  - ENGINEERING DEVELOPMENT (FIT)
  - ELECTRICAL HARNESS
- NEP SYSTEM - CENTAUR ADAPTER STRUCTURE

- COMPLETE TOOLING COSTS
- PROPELLANT SYSTEM TANK DEVELOPMENT
- NO SHIELD TECHNOLOGY DEVELOPMENT
- NO NON-NUCLEAR INSTRUMENTATION TECHNOLOGY DEVELOPMENT
- NO SHUTTLE LAUNCH/CENTAUR COSTS INCLUDED

The ground support equipment and the facilities and capital equipment identified for the NEP system development are summarized. This list is limited to those elements which are common to the development program options investigated.

COMMON KEY GUIDELINES AND ASSUMPTIONS SCHEDULES AND COSTS (CONTINUED)

COMMON GROUND SUPPORT EQUIPMENT

- NET SPACECRAFT SIMULATOR
- NEP SYSTEM SIMULATOR
- SHIPPING CONTAINERS
- TYPE ACCEPTANCE TEST EQUIPMENT
- FLIGHT ACCEPTANCE TEST EQUIPMENT
- HANDLING EQUIPMENT
- STRUCTURAL DEVELOPMENT HARDWARE SIMULATORS
- TOOLING

COMMON FACILITIES AND CAPITAL EQUIPMENT

- GPR FACILITY
- TFE FABRICATION FACILITY
- LIQUID METAL HANDLING FACILITY
- PROPELLANT HANDLING FACILITY
- ION ENGINE POWER INPUT SIMULATOR
- NEP SYSTEM ASSEMBLY AND TEST FACILITY
- NEP SYSTEM STORAGE FACILITY
- ION ENGINE ARRAY VACUUM TEST FACILITY
- THERMAL VACUUM TEST FACILITY

The scope of this NEP system development program study includes two main program options:

- A Baseline Program which is designed to provide a 20,000-hour (full power) NEP System for early 1980's multi-mission applications. A high degree of success is assured with a moderate cost by employing a comprehensive technology development effort coupled with limited prototype tests of key NEP subsystems.

- A minimum Program which is designed to provide a 10,000-hour (full power) NEP system for early 1980's multi-mission applications. Emphasis is placed primarily on technology development in order to minimize program costs. However, a moderate degree of success may be expected because of reduced NEP system full power life requirements, relative to the Baseline Program.

The cost impact of extensive use of beryllium structure are assessed.

The recurring costs associated with the liquid metal heat rejection subsystem of the NEP Power System are investigated. Gross estimates are presented for the total NEP system recurring costs.

SCOPE
NEP SYSTEM DEVELOPMENT COSTS

- BASELINE PROGRAM
  - 1983 LAUNCH
  - TECHNOLOGY READINESS - 20,000 HR TFE
  - TECHNOLOGY AND LIMITED PROTOTYPE DEVELOPMENT
- MINIMUM PROGRAM
  - 1983 LAUNCH
  - TECHNOLOGY READINESS - 10,000 HR TFE
  - EMPHASIS ON TECHNOLOGY DEVELOPMENT

- PERTURBATIONS
  - IMPACT OF BERYLLIUM STRUCTURE
- RECURRING COSTS
  - LIQUID METAL HEAT REJECTION
  - NEP FLIGHT SYSTEM ESTIMATES

Key assumptions, program costs and manpower requirements are presented for the Baseline NEP System Development Program. The Baseline Program incorporates a balanced effort of technology development, systems analysis and limited NEP subsystem prototype testing.

AGENDA

- PROGRAM OVERVIEW
  - BACKGROUND
  - OBJECTIVES
  - KEY GUIDELINES AND CONSTRAINTS
  - APPROACH
  - SCHEDULE AND STATUS SUMMARY
- PROGRAM RESULTS
  - DEVELOPMENT COSTS
    - COMMON GUIDELINES
    - BASELINE PROGRAM
    - MINIMUM PROGRAM
  - RECURRING COSTS
    - LIQUID METAL HEAT REJECTION SUBSYSTEM
    - FLIGHT NEP SYSTEM ESTIMATES
  - MISSION OPERATIONS
    - NEP SYSTEM STARTUP
    - COMMUNICATIONS
- CONCLUSIONS - PHASE II
- PLANNED FUTURE EFFORT - PHASE III

The Baseline NEP System development program objective is to provide an NEP system with a 20,000-hour full power capability for an early 1980's mission. This NEP system would perform all identified outer planet exploration missions, as well as the Comet Halley Rendezvous mission, with (attractive ~1000 kg) Net Spacecraft payloads. The approach employed is a high level of technology development effort coupled with prototype tests of the major NEP systems, the thrust system, and major elements of the power system.

The TREX and Ground Prototype Reactors are employed. The GPR also demonstrates the flight primary heat rejection loop, the shield and the flight reactor control system. The secondary heat rejection loop of the power system is prototyped independent of the reactor. The thrust system is derived from SEP technology. However, both partial and full ion engine array prototype systems are tested. These employ SEP technology in the NEP configuration and include complete power conditioning and thrust vector control systems.

Type acceptance is performed on a flight configured NEP system, except that mechanical and electrical reactor simulators are employed. Thermal vacuum performance is established during an extensive NEP system structural development program.

SPACE DIVISION

PARTICULAR GUIDELINES AND ASSUMPTIONS
NEP SYSTEM DEVELOPMENT BASELINE PROGRAM
TECHNOLOGY - SYSTEMS AND PROTOTYPE

- EARLY 1980'S LAUNCH OBJECTIVE
- NEP SYSTEM 50,000 HOUR LIFE OBJECTIVE
- KEY PROGRAM MILESTONES
  - PRELIMINARY MISSION APPROVAL
    - REPETITIVE 10,000 HOUR TFE LIFE
    - EXAMPLE 20,000 HOUR TFE LIFE
    - TECHNOLOGY READY FY 1978
    - TREX OPERATIONAL TEST COMPLETE
  - FINAL MISSION APPROVAL
    - GPR OPERATIONAL
    - REPETITIVE 20,000 HOUR TFE LIFE
    - FY 1980
    - STRUCTURAL DEVELOPMENT COMPLETE
- TREX AND GROUND PROTOTYPE DEVELOPMENT REACTORS
- GPR TEST MUST IMPACT FLIGHT REACTOR DESIGN
  - FLIGHT CONFIGURED
  - FLIGHT PRIMARY COOLANT LOOP
  - FLIGHT SHIELD
- THRUST SYSTEM DERIVED FROM SEP TECHNOLOGY
  - MODULE NUCLEAR ENVIRONMENTS TESTS
  - FULL NEP ARRAY PROTOTYPE TESTS

- POWER SYSTEM PROTOTYPE
- THRUST SYSTEM PROTOTYPE

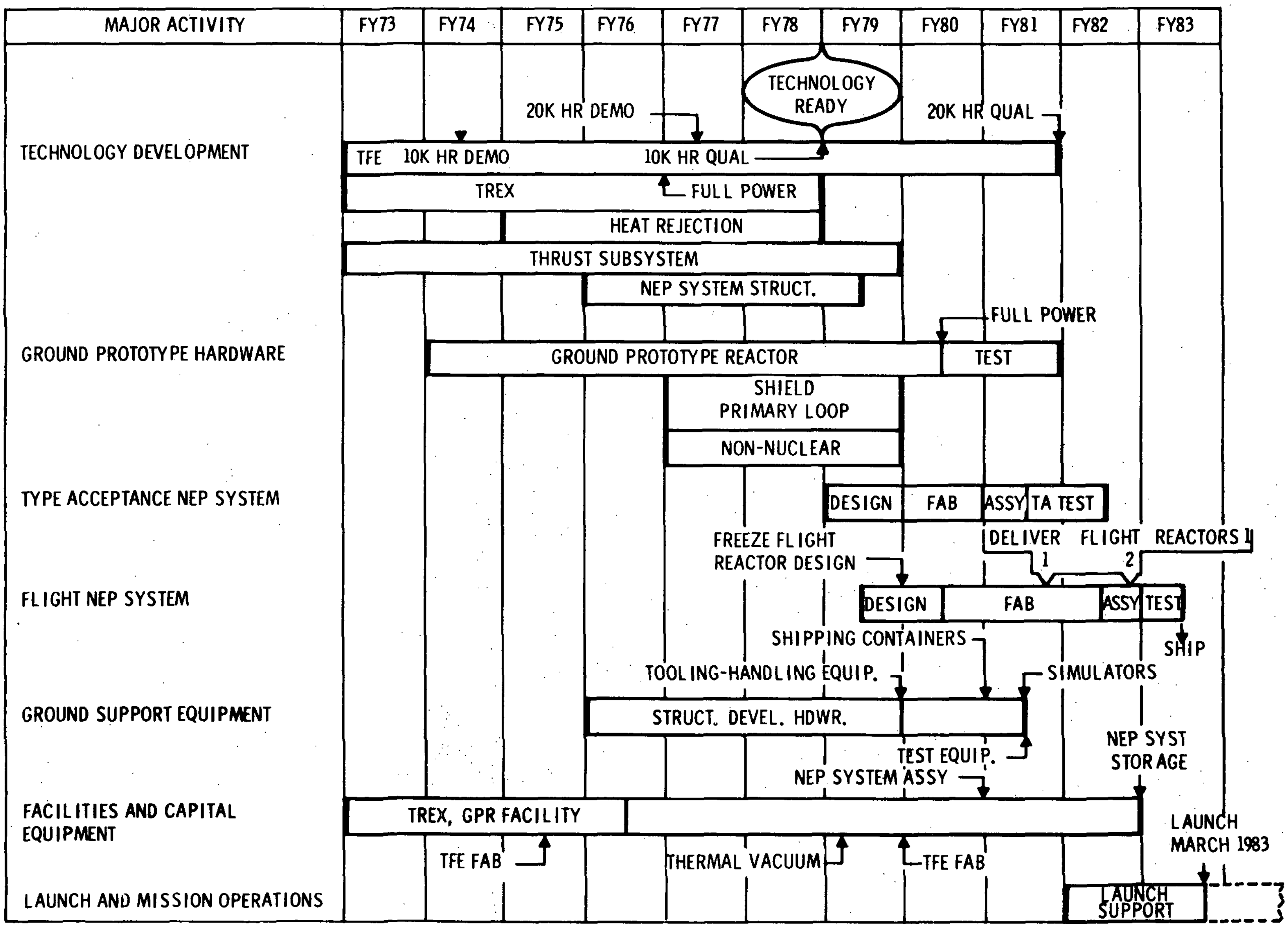
The summary schedule for the Baseline NEP System development program is presented. The Baseline program is assumed to initiate in Fiscal 1973, and extend for eleven years to meet an early 1980's launch objective for a 20,000 full power hour life NEP system.

Key elements of the Baseline program are:

- Inclusion of two ground reactor tests, TREX and a Ground Prototype Reactor.
- Strong dependence on SEP technology, although a partial ion engine array development test and a full ion engine array test are included to verify performance in the NEP configuration.
- Early requirements for GSE, particularly structural simulation, and for facilities for reactor tests. The NEP System assembly test and checkout facility is required about three years before launch.
- A TFE design with proven continuous 20,000 life capability is qualified two years before launch.
- Technology ready and preliminary mission approval occur in FY 1978 after demonstration of the feasibility of a 20,000-hour TFE life, and with the qualification of the 10,000-hour life TFE. The TA NEP system design is initiated.

SPACE DIVISION

SUMMARY SCHEDULE
BASELINE NEP SYSTEM PROGRAM



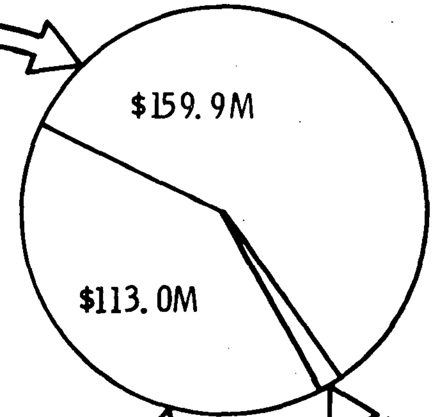
Baseline NEP System development program cost elements are regrouped to present program costs in terms of basic development, the total flight program and mission support. The $160M development program represents about 58 percent of the total. The $113M flight program cost is about 41 percent of the total. The contractor mission support function constitutes less than one percent of the program total. Required facilities will add $35.4M to these costs.

SPACE DIVISION

COST SUMMARY
BASELINE NEP SYSTEM PROGRAM

DEVELOPMENT

REACTOR/TFE DEVELOPMENT	$ 46.9M
GROUND PROTOTYPE HARDWARE	36.2
NON-NUCLEAR TECHNOLOGY	40.0
GROUND SUPPORT EQUIPMENT	13.7
SYSTEMS ENGINEERING	12.4
PROGRAM MANAGEMENT	10.7
	159.9*



FLIGHT

TYPE ACCEPTANCE NEP SYSTEM	$31.6M
FLIGHT NEP SYSTEM (ONE)	$35.2
SPARE (SECOND) FLIGHT REACTOR	8.5
GROUND SUPPORT EQUIPMENT	12.6
FLIGHT SAFETY	8.2
SYSTEMS ENGINEERING	9.1
PROGRAMING MANAGEMENT	7.8
	113.0*

*FACILITY REQUIREMENTS

DEVELOPMENT	$20.1M
FLIGHT	$15.4
	$35.4M

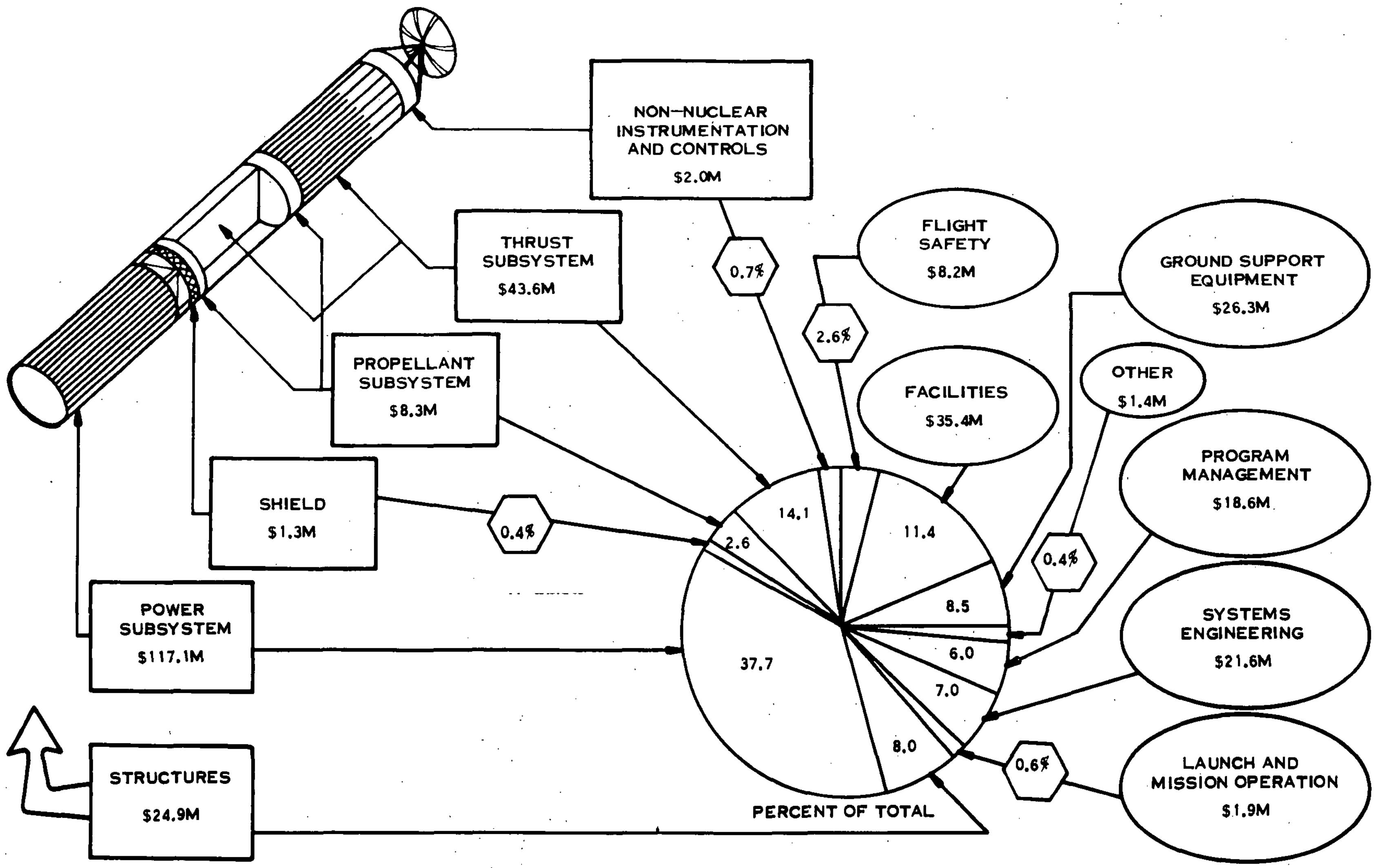
MISSION SUPPORT

LAUNCH AND MISSION OPERATIONS	$ 1.9M
PROGRAM MANAGEMENT	0.1
SYSTEMS ENGINEERING	0.1
FACILITIES	GFE
	$ 2.1M

This breakdown of the Baseline NEP System development program emphasizes the cost elements of the NEP System hardware. The percent of the total program costs are also shown. Cost data particular to this chart are:

- Non-nuclear instrumentation and controls
- Thrust subsystem
- Propellant subsystem
- Shield
- Power subsystem
- Structural development

KEY COST ELEMENTS
BASELINE NEP SYSTEM PROGRAM



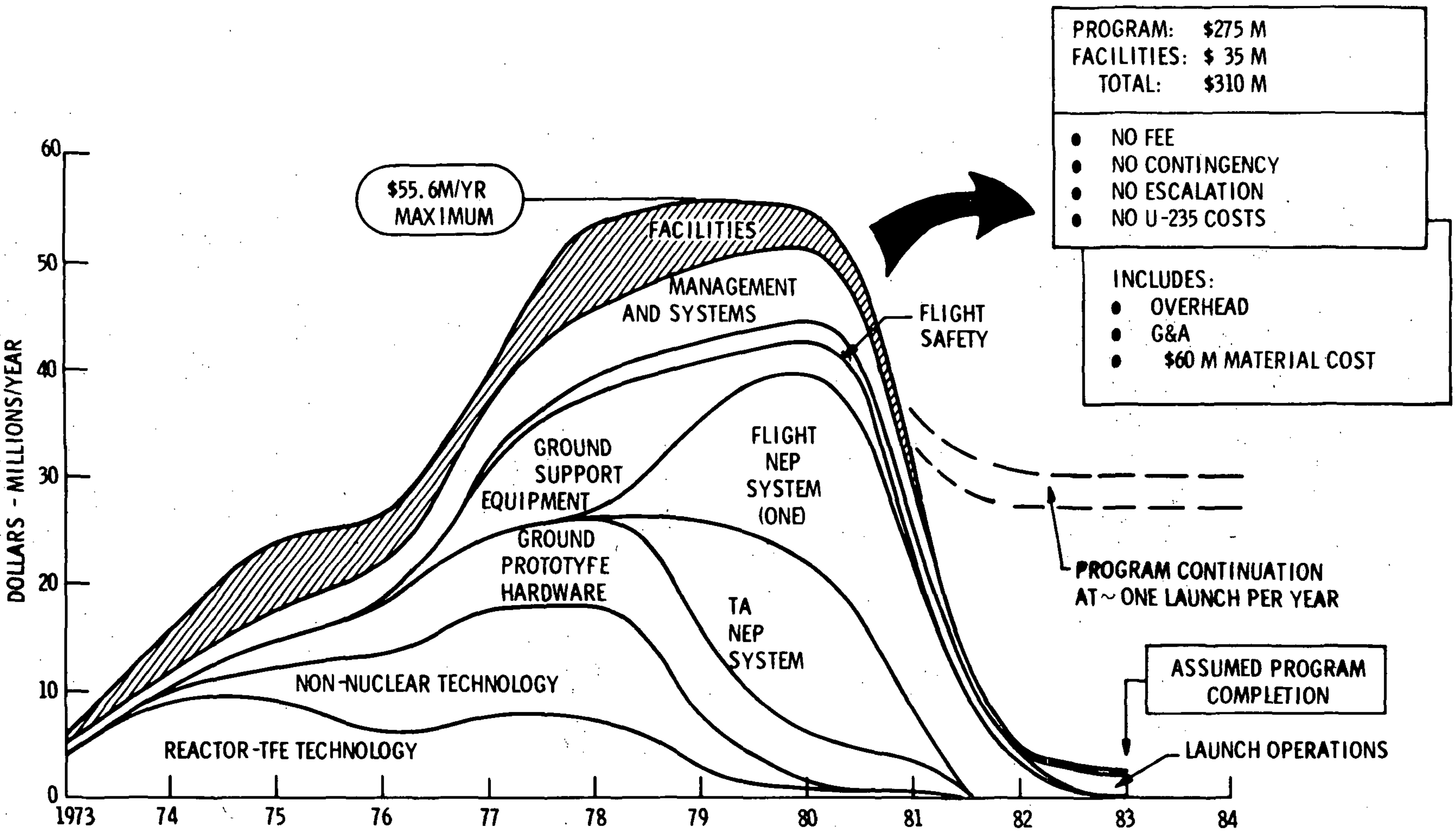
Program costs are presented as a function of fiscal year for the $275M Baseline NEP System development program. Peak costs of $56M are estimated for Fiscal 1979. These costs include overhead, G&A, and a total of ~$60M in material costs. These costs are based on Fiscal 1972 dollars, and do <u>not</u> include any allowance for contingency, escalation, or U-235 fuel costs.

No fee is included in these costs.

The contribution of the major task elements are presented. There is a clear flow of funding from technology, to ground prototype hardware, to the TA NEP system, and to the Flight NEP systems. The early requirement for Facilities and GSE and their impact on annual program funding requirements is clearly indicated.

SPACE DIVISION

BASELINE NEP SYSTEM PROGRAM TOTAL DOLLARS BY FISCAL YEAR



Total dollars for key program elements are presented as a function of fiscal year. Key program milestones are indicated.

The Baseline NEP System development program incorporates a $27M TFE development program. The total cost for the two test reactors, including test operations, is $48M. Other technology development, including structures and ion engine array, accounts for $48M. These totals do not include related program management and safety.

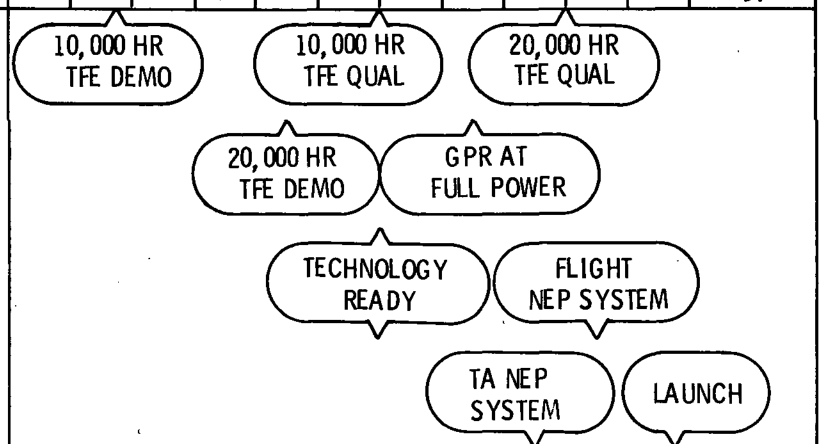
Total TA and Flight NEP Systems costs are $76M. Flight safety costs are about $8M. Management and Systems Engineering are $42M (Launch and Mission Operations are included at $2M). Total GSE costs are $26M. Facility costs add $35M to the $275M NEP System program.

Peak program funding is $56M in Fiscal 1979.

SPACE DIVISION

TOTAL DOLLARS BY KEY PROGRAM ELEMENTS
BASELINE NEP SYSTEM PROGRAM

PROGRAM ELEMENT			FISCAL YEAR 73	74	75	76	77	78	79	80	81	82	83	TOTALS
POWER SUBSYSTEM DEVELOPMENT														
	TFE DEVELOPMENT AND DEMONSTRATION		3	4	4	4	4	4	2	1	1			$27M
	REACTORS	TREX AND TEST OPERATIONS	1	5	4	3	3	4						20
		GPR AND TEST OPERATIONS			3	4	5	4	5	4	3			28
	OTHER POWER SUBSYSTEM TECHNOLOGY				1	3	3	2	2					11
THRUST SUBSYSTEM DEVELOPMENT				1	2	5	9	12	7	1				37



PROGRAM ELEMENT		73	74	75	76	77	78	79	80	81	82	83	TOTALS
TYPE ACCEPTANCE AND FLIGHT NEP SYSTEMS							1	20	33	19	3		76
FLIGHT SAFETY						1	1	2	1	1	1	1	8
MANAGEMENT, SYSTEM AND LAUNCH		1	2	2	3	5	7	7	7	4	2	2	42
GROUND SUPPORT EQUIPMENT					1	5	11	5	3	1			26
	TOTALS	5	12	16	23	35	46	50	50	29	6	3	$275M
FACILITIES		1	3	7	3	3	7	6	3	1	1		35
	TOTALS	6	15	23	26	38	53	56	53	30	7	3	$310M

Key assumptions, program costs and manpower requirements are presented for a Minimum NEP System Development Program. This minimum program emphasizes technology development and systems analysis, with little prototype development.

AGENDA

- PROGRAM OVERVIEW
  - BACKGROUND
  - OBJECTIVES
  - KEY GUIDELINES AND CONSTRAINTS
  - APPROACH
  - SCHEDULE AND STATUS SUMMARY
- PROGRAM RESULTS
  - DEVELOPMENT COSTS
    - COMMON GUIDELINES
    - BASELINE PROGRAM
    - MINIMUM PROGRAM
  - RECURRING COSTS
    - LIQUID METAL HEAT REJECTION SUBSYSTEM
    - FLIGHT NEP SYSTEM ESTIMATES
  - MISSION OPERATIONS
    - NEP SYSTEM STARTUP
    - COMMUNICATIONS
- CONCLUSIONS - PHASE II
- PLANNED FUTURE EFFORT - PHASE III

The Minimum NEP System development program objective is to provide an NEP System with a 10,000-hour full power capability for early 1980's missions. This NEP System would perform most identified outer planets with reduced Net Spacecraft payloads or extended mission times. It could perform the Comet Halley rendezvous mission, but the risk would be increased. As an objective, this development approach minimizes annual costs through the first five years of the program. The approach employed assumes a high level technology development effort, with emphasis on nuclear component development.

The TREX reactor is not included in this program in order to reduce costs early in the program. TFE life capability is demonstrated in the TFE development program, using TRIGA-type test reactors. A Ground Prototype Reactor demonstration is included in the program which does impact the design of the Flight NEP System. The GPR test includes flight-type primary coolant loop, shield, and reactor control system.

The Thrust system is derived completely from SEP technology, except for partial array performance tests in the NEP configuration. Power conditioning nuclear environment tests are also included.

As in the Baseline Program, Type Acceptance is performed on a flight configured NEP System, except that mechanical and electrical reactor simulators are employed. Thermal vacuum performance is established during an extensive NEP System structural development program.

SPACE DIVISION

PARTICULAR GUIDELINES AND ASSUMPTIONS
NEP SYSTEM DEVELOPMENT MINIMUM PROGRAM
TECHNOLOGY AND SYSTEMS ANALYSIS

- EARLY 1980'S LAUNCH OBJECTIVE
- NEP SYSTEM 10,000 FULL POWER HOUR INITIAL LIFE OBJECTIVE
- MINIMIZE COSTS THROUGH FY 1976 (~$10M/YEAR)
- NO TREX - NO TREX FACILITY
- KEY PROGRAM MILESTONES
  - FINAL MISSION APPROVAL
    - REPETITIVE 10,000 HOUR TFE
    - TECHNOLOGY READY FY 1978
- GROUND PROTOTYPE REACTOR
- NO THRUST SUBSYSTEM DEVELOPMENT OR PROTOTYPE TESTS
  - COMPLETE DEPENDENCE OF SEP PROGRAM

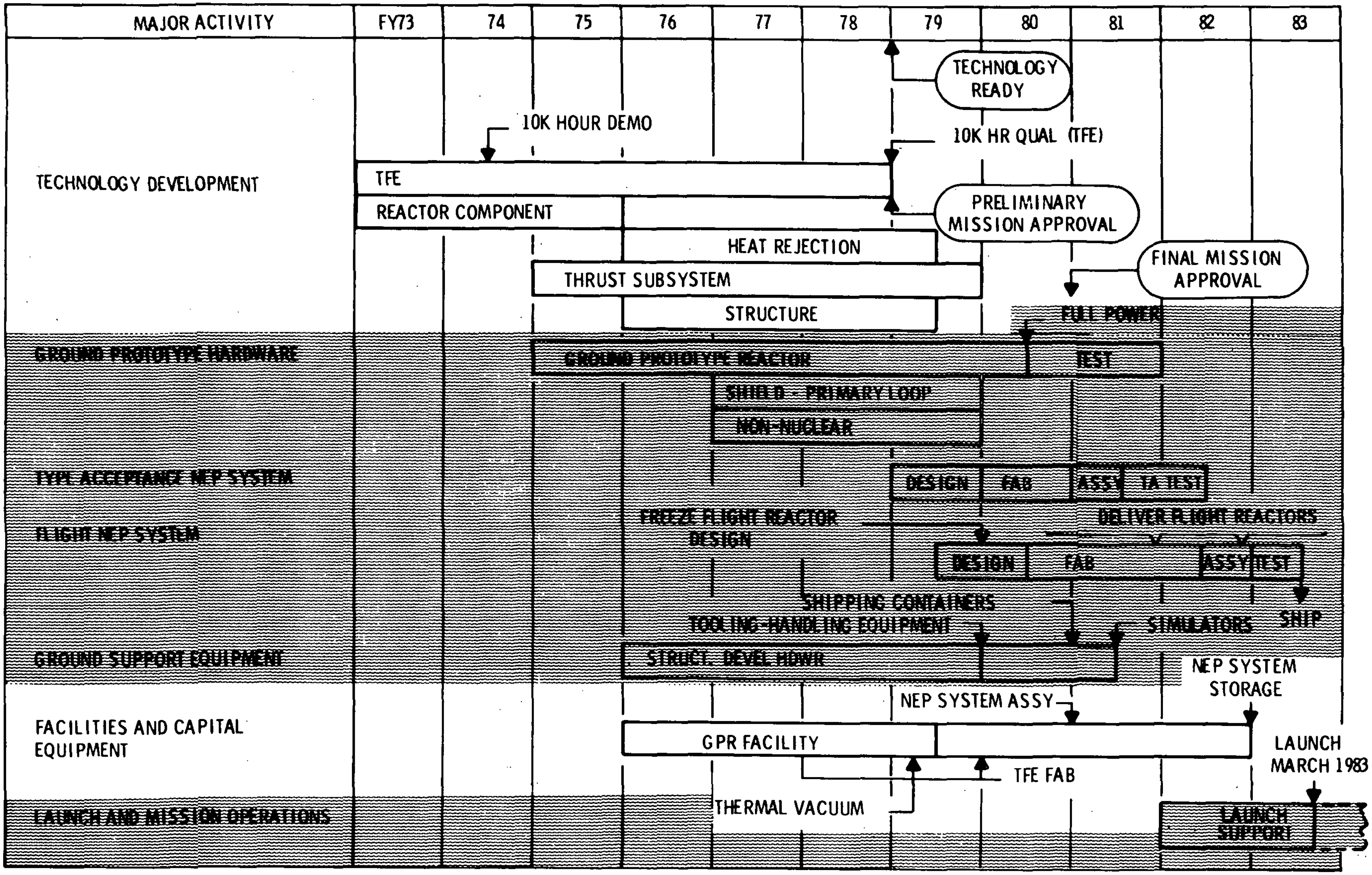
- NO PROTOTYPE SYSTEM TESTS
- COMPONENT DEVELOPMENT ONLY

The summary schedule for the Minimum NEP System development program is presented. This minimum program is assumed to initiate in Fiscal 1973, and extend for eleven years to meet an early 1980's launch objective for a 10,000 full power hour life NEP system.

Key elements of this minimum program are:

- Program costs are minimized during the first five years.
- Only one ground reactor test is included.
- Major dependence on SEP technology. The only development included for the thrust and propellant systems are for the integrated propellant-shield tank, power conditioning nuclear environment tests, and a partial array ion engine test.
- Early requirements for GSE, particularly structural simulators, remain in common with the Baseline program. Facility requirements are almost identical, except that no TREX facility is required. The schedule for facility availability is delayed one to two years, relative to the Baseline Program.
- Technology readiness and final mission approval occur in Fiscal 1978 with the demonstration of continuous 10,000-hour TFE life capability.

SUMMARY SCHEDULE
MINIMUM NEP SYSTEM PROGRAM



Minimum NEP System development program cost elements are grouped to present program costs in terms of basic development, the total flight program and mission support. The $118M development program represents about 50 percent of the total. The $113M flight program cost is about 49 percent of the total. The major change, relative to the Baseline Program, is a $42M decrease in the development program. The contractor mission support function constitutes less than one percent of the program total.

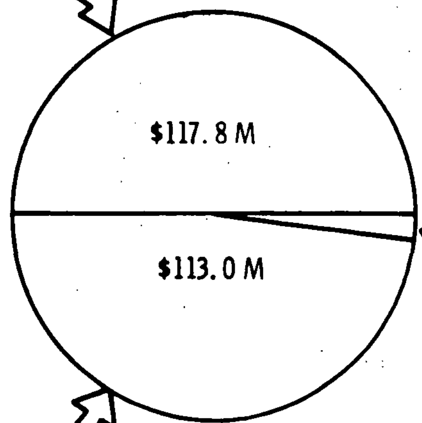
COST SUMMARY
MINIMUM NEP SYSTEM PROGRAM

DEVELOPMENT

REACTOR / TFE DEVELOPMENT	$23.2 M
GROUND PROTOTYPE HARDWARE	36.2
NON-NUCLEAR TECHNOLOGY	31.8
GROUND SUPPORT EQUIPMENT	13.7
SYSTEMS ENGINEERING	6.8
PROGRAM MANAGEMENT	6.1
	$ 117.8 M*

FLIGHT

TYPE ACCEPTANCE NEP SYSTEM	$31.6 M
FLIGHT NEP SYSTEM (ONE)	35.2
SPARE (SECOND FLIGHT REACTOR	8.5
GROUND SUPPORT EQUIPMENT	12.6
FLIGHT SAFETY	8.2
SYSTEMS ENGINEERING	9.1
PROGRAM MANAGEMENT	7.8
	$ 113.0 M*



***FACILITY REQUIREMENTS**

DEVELOPMENT	$20.1 M
FLIGHT	15.3
	$35.4 M

MISSION SUPPORT

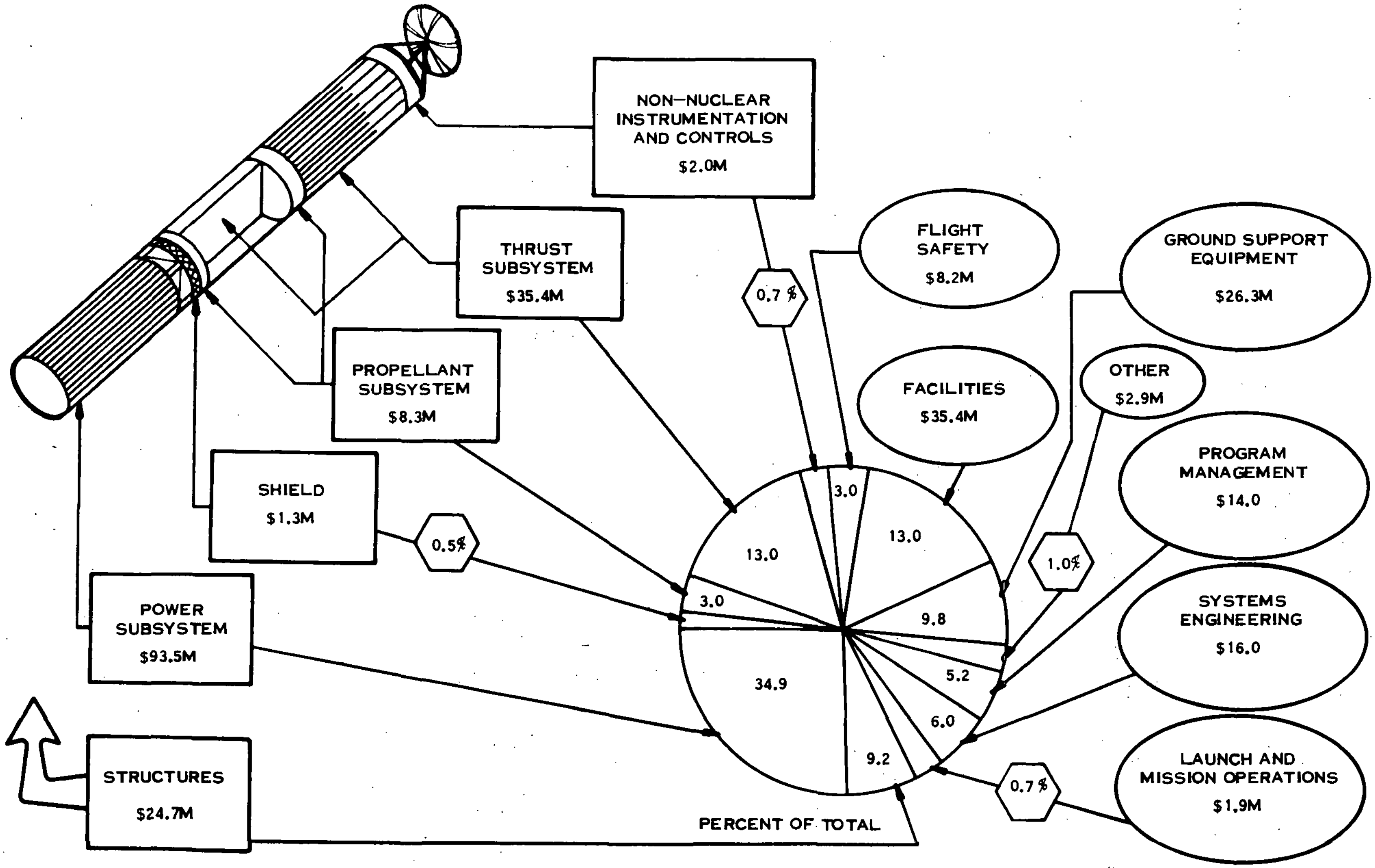
LAUNCH AND MISSION OPERATIONS	$1.9 M
PROGRAM MANAGEMENT	0.1
SYSTEMS ENGINEERING	0.1
FACILITIES	GFE
	$2.1 M

This breakdown of the Minimum NEP System development program emphasizes the cost elements of the NEP System hardware. The percent of the total program costs are also shown. Cost data particular to this chart are:

- Non-nuclear instrumentation and controls
- Thrust subsystem
- Propellant subsystem
- Shield
- Power subsystem
- Structural development

SPACE DIVISION

KEY COST ELEMENTS
MINIMUM NEP SYSTEM PROGRAM

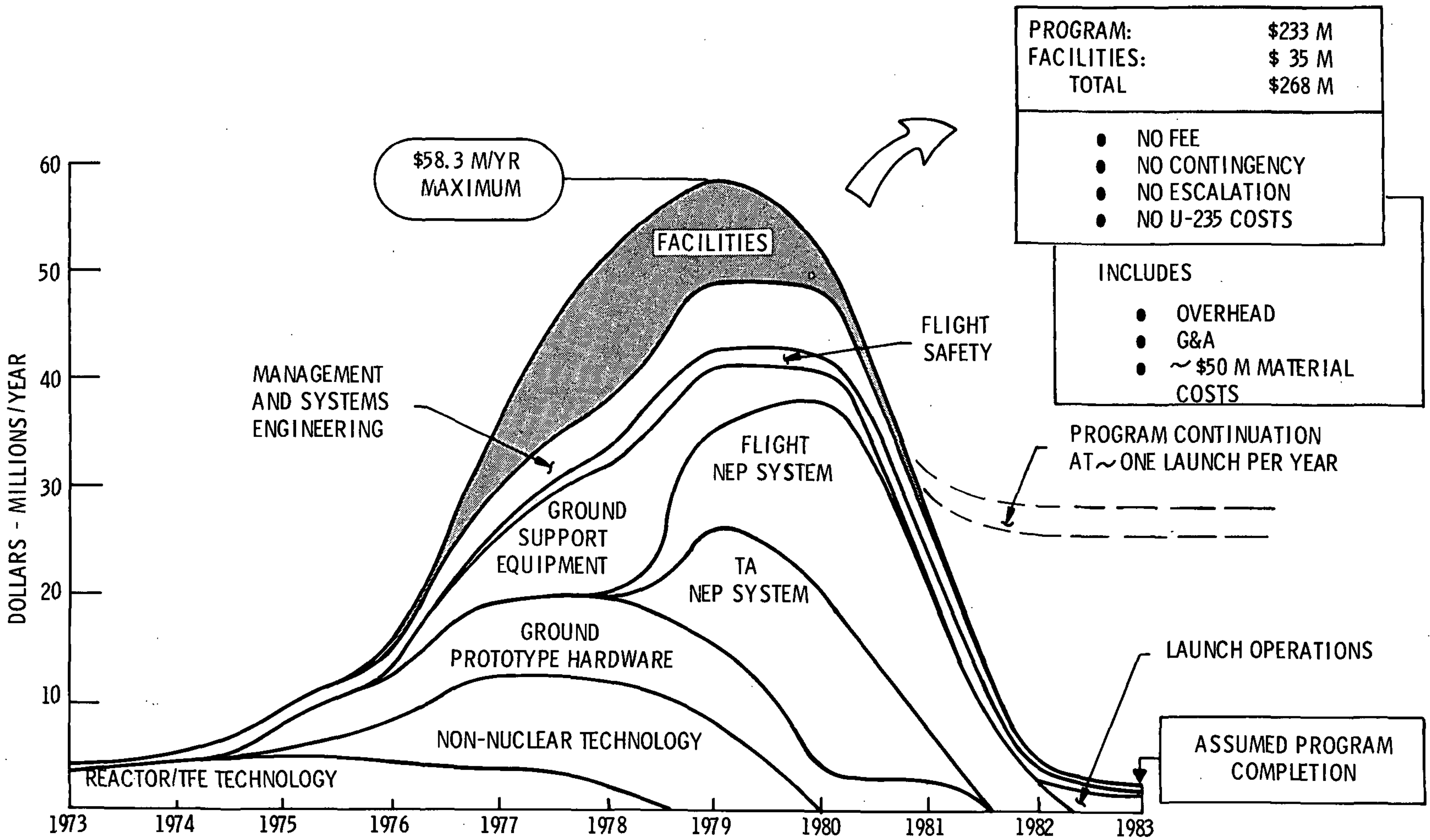


Program costs are presented as a function of fiscal year for the \$233M Minimum NEP System development program. Peak costs of \$58.3M are estimated for Fiscal 1979. These costs include overhead, G&A, and a total of $\sim$\$50M in material costs. These costs are based on Fiscal 1972 dollars, and do <u>not</u> include any allowance for contingency, escalation, or U-235 fuel costs.

No fee is included in these costs.

The contribution of the major task elements are presented. There is a clear flow of funding from technology, to ground prototype hardware, to the TA NEP system and to the Flight NEP systems. The early requirement for Facilities and GSE and their impact on annual program funding requirements, is clearly indicated.

MINIMUM NEP SYSTEM PROGRAM
TOTAL DOLLARS BY FISCAL YEAR



Total dollars for key program elements are presented as a function of fiscal year. Key program milestones are indicated.

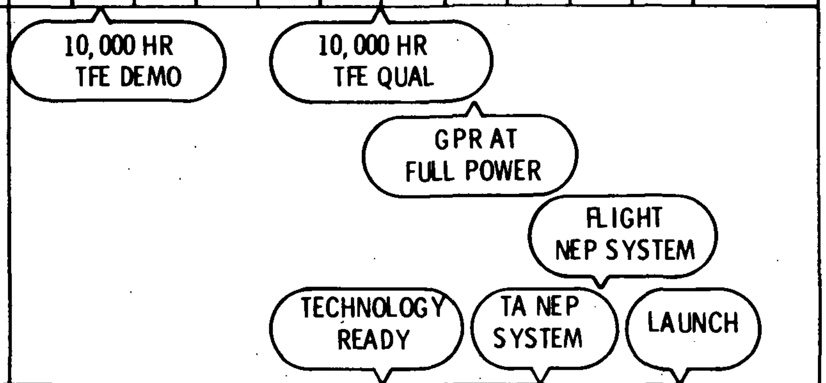
The Minimum NEP System development program incorporates a $23M TFE development program. The total cost for the test reactor, including test operations, is $28M. Other technology development, including structures, accounts for $40M. These totals do not include related program management and safety.

Total TA and Flight NEP Systems costs are $76M. Flight safety costs are about $8M. Management and System Engineering are $32M (Launch and Mission Operations are included at $2M). Total GSE and Facility costs are $61M.

Peak program funding is $58M in Fiscal 1979.

TOTAL DOLLARS BY KEY PROGRAM ELEMENTS
MINIMUM NEP SYSTEM PROGRAM

PROGRAM ELEMENT		FISCAL YEAR 73	74	75	76	77	78	79	80	81	82	83	TOTALS
POWER SUBSYSTEM DEVELOPMENT													
	TFE DEVELOPMENT AND DEMONSTRATION	4	4	5	4	4	2	-	-	-	-	-	$ 23M
	REACTOR – GPR AND TEST OPERATIONS			3	4	5	4	5	4	3			28
	OTHER POWER SUBSYSTEM TECHNOLOGY				2	3	4	2					11
THRUST SUBSYSTEM DEVELOPMENT				1	2	7	10	9					29



PROGRAM ELEMENT	73	74	75	76	77	78	79	80	81	82	83	TOTALS
TYPE ACCEPTANCE AND FLIGHT NEP SYSTEMS						1	20	33	19	3		76
FLIGHT SAFETY					1	1	2	1	1	1	1	8
MANAGEMENT, SYSTEMS AND LAUNCH	1	1	1	2	4	4	6	6	3	2	2	32
GROUND SUPPORT EQUIPMENT				1	5	11	5	3	1			26
TOTALS	5	5	10	15	29	37	49	47	27	6	3	$233M
FACILITIES				1	6	14	9	3	2			35
TOTALS	5	5	10	16	35	51	58	50	29	6	3	$268M

Key programmatic options and schedule milestones are compared for the NEP System development program alternates investigated. These alternates employ an extensive TFE development program and a Ground Prototype (flight configured) reactor test. In addition, the Baseline includes an earlier TREX reactor, which is not necessarily flight configured.

The Minimum Program depends significantly on the SEP program for the thrust subsystem technology. Partial ion engine tests are included, and limited power conditioning nuclear environment tests are scheduled. The Baseline Program includes one partial ion array test and one full ion engine array test, utilizing SEP technology configured for the NEP system.

The Baseline Program is assumed to be technology ready in FY 78, with the demonstration of continuous 10,000-hour TFE full power life capability, and potential for a similar 20,000-hour life. Mission approval follows in FY 80. Mission approval and technology readiness for the Minimum Program occurs in Fiscal 1978, because its mission life objective is assumed at 10,000 full power hours.

PARTICULAR GUIDELINES AND CONSTRAINTS NEP SYSTEM DEVELOPMENT OPTIONS

	TFE DEVELOPMENT	TREX	GROUND PROTOTYPE REACTOR TEST	ION ENGINE TESTS	PROTOTYPE ION ENGINE ARRAY LIFE TEST	TECHNOLOGY READY	PRELIMINARY MISSION APPROVAL	FINAL MISSION APPROVAL	10,000 HOUR TFE QUALIFICATION	20,000 HOUR TFE QUALIFICATION	LAUNCH
BASELINE PROGRAM 20,000 FULL POWER HOUR MISSION	Y	Y	Y	Y	Y	FY 78	FY 78	FY 80	FY 78	FY 81	FY 83
MINIMUM PROGRAM 10,000 FULL POWER HOUR MISSION	Y	N	Y	Y	N	FY 78	FY 78	FY 78	FY 78	N	FY 83

Y = YES — INCLUDED

N = NOT INCLUDED

The major cost elements of the two NEP System development program alternates are compared. The Program Management and Systems Engineering functions are seen to be a fairly constant percent of the totals at 6 to 7 percent, and 7 to 8 percent, respectively. Flight safety is 3 to 4 percent for the Baseline and Minimum Programs. Ground Prototype Hardware test percentages vary from 13 to 16 percent.

Total dollar values are constant for TA and Flight NEP Systems for both programs. Launch and Mission Operations also show constant dollars as do GSE total dollars and total facility dollars.

SPACE DIVISION

DOLLAR SUMMARY - NEP SYSTEM DEVELOPMENT PROGRAM COMPARISON

	BASELINE PROGRAM		MINIMUM PROGRAM	
	$M	PERCENT	$M	PERCENT
PROGRAM MANAGEMENT	$ 18.6	6.7%	$ 14.0	6.0%
SYSTEMS ENGINEERING	21.6	7.8	16.0	7.0
FLIGHT SAFETY	8.2	3.0	8.2	3.5
TECHNOLOGY DEVELOPMENT	86.9	31.7	55.1	23.6
GROUND PROTOTYPE HARDWARE	36.2	13.2	36.2	15.5
TYPE ACCEPTANCE NEP SYSTEM	31.6	11.5	31.6	13.5
FLIGHT NEP SYSTEM (ONE)*	43.7	15.9	43.7	18.8
GROUND SUPPORT EQUIPMENT	26.3	9.5	26.3	11.3
LAUNCH AND MISSION OPERATIONS**	1.9	0.7	1.9	0.8
SUB TOTALS	$275.0	100.0%	$233.0	100.0%
FACILITIES	35.0		35.0	
TOTALS	$310.0		$268.0	

- 1972 DOLLARS
- NO ESCALATION
- NO FEE
- NO U-235 COSTS

*INCLUDES ONE SPARE REACTOR AT $8.5M

**TWO SHUTTLE/CENTAUR LAUNCHES AT $13.7M EACH NOT INCLUDED

The impact of extensive beryllium structure on the NEP system development costs, and upon NEP system units costs was assessed. The use of beryllium structure will increase the NEP system development costs by approximately \$15-million. The bulk of these costs are associated with the NEP thrust and propellant systems structural development and related structural simulators; the dynamic, mass and engineering (fit) mock-up. Only about \$1.0-million is related to the development of the power system if a beryllium-stainless radiator is required.

The extensive use of beryllium in production-type NEP systems such as the CNS Test, TA hardware and flight NEP systems will increase unit NEP system costs by about \$3.75-million. More than 25 percent (\$1.0-million) is tied up in the required NEP System-to-Centaur adapter structure. The largest contributor is the Thrust System (\$2.10-million). Unit beryllium stainless main heat rejection radiators add about \$400-thousand. At the 120 kWe electric power level evaluated, the specific unit cost for beryllium structure is about \$30K/kWe.

The identified impact of extensive use of beryllium structure on NEP system development and unit costs is independent of the extent of other development imposed; whether a minimum, baseline, major or other program.

BERYLLIUM STRUCTURE COST ASSESSMENT

NEP SYSTEM DEVELOPMENT	
BERYLLIUM STAINLESS RADIATOR	$ 1.25M
NEP SYSTEM STRUCTURE	10.00
STRUCTURAL SIMULATORS	4.00
TOTAL	$15.25M

NEP SYSTEM UNIT COSTS	
BERYLLIUM STAINLESS RADIATOR	$0.40M
BERYLLIUM ION ENGINE ARRAY STRUCTURE	0.75
POWER CONDITIONING RADIATOR AND SUPPORT STRUCTURE	1.35
NEP SYSTEM - CENTAUR ADAPTER STRUCTURE	1.00
TOTAL	$3.50M

Recurring costs are summarized for the NEP system liquid metal heat rejection subsystem. A preliminary assessment of total NEP system recurring costs is discussed.

AGENDA

- PROGRAM OVERVIEW
  - BACKGROUND
  - OBJECTIVES
  - KEY GUIDELINES AND CONSTRAINTS
  - APPROACH
  - SCHEDULE AND STATUS SUMMARY
- PROGRAM RESULTS
  - DEVELOPMENT COSTS
    - COMMON GUIDELINES
    - BASELINE PROGRAM
    - MINIMUM PROGRAM
  - RECURRING COSTS
    - LIQUID METAL HEAT REJECTION SUBSYSTEM
    - FLIGHT NEP SYSTEM ESTIMATES
  - MISSION OPERATIONS
    - NEP SYSTEM STARTUP
    - COMMUNICATIONS
- CONCLUSIONS - PHASE II
- PLANNED FUTURE EFFORT - PHASE III

The results of work performed under a separate, but related, contract are presented. The goal of this work was to take the liquid metal heat rejection subsystem (X3XX) and estimate the cost of producing eight additional units in eight more years after the first two spacecraft were delivered.

The liquid metal heat rejection subsystem was assumed to consist of the primary (reactor) loop ducting and accumulator, four independent radiator loops and their associated ducting, accumulators, and radiator sections, the intermediate heat exchanger (which separate the primary loop from the radiator loops), and a pair of EM pumps in series to drive all five loops. Guidelines and assumptions used in this study are presented.

It was assumed that the flight hardware built and flown as a result of the development program (the first two spacecraft) were acceptable with no additional engineering changes. In one sense this is unrealistic, since no series of spacecraft has been completely frozen as to design after only two launches. It was a ground rule for this study, however. The availability of jigs, tooling, and fixtures is, therefore, assumed.

The initial costs were figured on the basis of the requested one per year production rate. GE manufacturing consultants felt that this schedule precluded any real learning-curve gains, and felt that a compressed schedule might lower total cost significantly as long as extra facilities were not required.

As was the case during the development program, no full-power, high-temperature testing is employed.

The most serious problem was establishing cost estimates for the production of components and systems which would be the subject of a multimillion dollar development program, and whose design would not be fixed for a minimum of five years. The approach selected involved two separate techniques. First, the production costs estimated in the 6300 series tasks of the development program provided a basis for a per-copy price for a system; however, it was initially thought that these costs might be unrealistic for true production manufacturing. Therefore, a second estimate was obtained in a quite different fashion.

The General Electric Company has a group of Corporate Consulting Services which can be used by Company components to augment their own expertise. These personnel, Manufacturing Engineering Services (MES), independently evaluated the cost of producing the components required for the liquid metal heat rejection subsystem. For each component, a sketch or design of a similar component was selected. These designs were either ones built for testing under NASA contract, or designed as part of a proposal or study effort. For example, the EM pump was based on one designed for a thermionic reactor system proposal while the accumulator was based on a SNAP-8 design.

SPACE DIVISION

RECURRING COSTS
LIQUID METAL HEAT REJECTION SUBSYSTEM
GUIDELINES AND ASSUMPTIONS

SYSTEM DEFINITION

- THE SYSTEM BUILT DURING THE 6300 TASK IS ACCEPTABLE WITH NO ENGINEERING CHANGES REQUIRED.
- ALL TOOLING, JIGS, FIXTURES ARE AVAILABLE FOR FURTHER USE.
- ACCEPTABLE, ALTHOUGH NOT NECESSARILY OPTIMUM, MANUFACTURING PROCESSES HAVE BEEN DEVELOPED.

SCHEDULE AND COSTS

- INITIAL COSTS WILL BE FIGURED OVER AN EIGHT-YEAR PERIOD, ONE UNIT PER YEAR.
- THE EFFECT ON UNIT COST OF COMPRESSING THE PRODUCTION SCHEDULE TO AN OPTIMUM LENGTH WILL BE ESTIMATED.
- NO FULL SYSTEM LIQUID METAL TESTING WILL BE EMPLOYED.

COSTING APPROACH

- SPECIMEN COMPONENTS SIMILAR TO THE ANTICIPATED DESIGNS WERE SELECTED.
- MANUFACTURING ESTIMATES WERE OBTAINED FROM GENERAL ELECTRIC CORPORATE CONSULTING SERVICES (MANUFACTURING ENGINEERING SERVICES) AS WELL AS FROM PRIOR GE EXPERIENCE.
- ALL COSTS WERE PUT ON A PER COPY BASIS.

The results of the liquid metal heat rejection subsystem recurring cost study are summarized. These costs are markedly lower than those based on the development program, even when the cost of fixtures, tooling, and jigs are accounted for.

The per-copy cost of a complete liquid metal heat rejection subsystem is estimated at $3.7M based on the development program, with a total of about 180,000 man-hours. This value does not include design and Q/C costs, which bring the total to $4.035M.

The comparison below clearly shows the difference between the unit costs from the development program, and those from the production program.

	Per Unit Cost	
Item	Development Program (63XX)	Production Cost
Radiator	$ 1934K	$ 889K
Heat Exchanger	200	93
EM Pumps	800	200
Accumulators	501	115
Ducting	300	76
Total	$ 3735K	$1373K
Design and Q/C Costs are not included in this estimate.		

SPACE DIVISION

LIQUID METAL HEAT REJECTION SUBSYSTEM
COST PER UNIT (EIGHT UNITS IN EIGHT YEARS)

MAN HOURS	RADIATOR	HEAT EXCHANGER	EM PUMPS	ACCUMULATORS	DUCTING	TOTAL
ENGINEER	2000	500	1000	700	500	4700
TECHNICIAN	3460	900	1300	1100	450	7210
SHOP	13250	4250	9500	4660	3190	34850
TOTAL	18710	5650	11800	6460	4140	46760
COSTS ($000)						
APPLIED LABOR	108	34	69	40	25	276
OVERHEAD	130	41	83	48	30	332
LABOR COST	238	75	152	88	55	608
MATERIAL	570	10	30	17	15	642
SUBTOTAL	808	85	182	105	70	1250
G&A	81	8	18	10	7	123
TOTAL COST	889	93	200	115	77	1373

A detailed comparison of the cost for the main heat rejection radiator is shown, which is typical of the results for the other components.

It is immediately apparent that the manpower levels specified are very different. Three reasons help explain the discrepancy. First, the "First Set" estimates were made with the feeling that reasonable development work would be needed. Second, manufacturing processes still need development and third, these "First Set" units are assumed to be produced in a one-of-a-kind environment.

Careful consideration of these data lead to the conclusion that the recurring cost estimates are as accurate as can be generated at this time.

LIQUID METAL HEAT REJECTION SUBSYSTEM
COST PER UNIT, RADIATOR

MAN HOURS	FIRST SET FLIGHT HARDWARE (LESS TOOLING)	PRODUCTION COST (8 IN 8 YEARS)
ENGINEER	6300	2000
TECHNICIAN	25060	3460
SHOP	57200	13250
TOTAL	88560	18710
COSTS ($000)		
APPLIED LABOR	556	108
OVERHEAD	667	130
LABOR COST	1223	238
MATERIAL	600	570
SUBTOTAL	1823	808
G&A	182	81
TOTAL COST	2005	898

It is economically advantageous to compress the schedule up to the point at which additional jigs, fixtures, and major tooling were required. In this way, maximum learning on the part of the workmen would occur. In addition, the test and engineering fucntion would be fully occupied with an additional saving.

In all of the work on this program, the high cost of fabricated beryllium showed up as a major item. If the missions planned can afford to use heavier material such as copper - stainless steel for the radiator fins, approximately $400K/unit can be saved.

The first variation shows a savings of $185K per heat rejection subsystem unit or about 13% while the second variation shows a savings of $400K/unit or 29%. The results of this portion of the study show that a very real saving can be achieved by freezing the design of the liquid metal heat rejection subsystem and going into a limited production mode.

LIQUID METAL HEAT REJECTION SUBSYSTEM COST MODIFIERS

A. PRODUCE EIGHT UNITS IN APPROXIMATELY THREE YEARS

- GET "LEARNING CURVE" EFFECT, SAVE $85K/UNIT
- LOWER ENGINEERING AND TECHNICIAN COSTS, SAVE $100K/UNIT
- OPTIMUM USE OF FACILITIES

B. MAKE RADIATOR OUT OF COPPER-STAINLESS

- BERYLLIUM IS EXPENSIVE IN FABRICATED FORMS, SAVE $400K/UNIT
- REDUCE DEVELOPMENT PROGRAM COST

Estimated total recurring costs for the Flight NEP System are presented. The first Flight NEP System costed for the development program options totals \$35.2M. It is estimated that the cost of the second of these two units is about 80 percent of the cost of the first unit, if these two are built consecutively over a two-year period. It is possible that the cost of subsequent units could approach \$25M, or 70 percent of the cost of the first unit.

SPACE DIVISION

ESTIMATED RECURRING COSTS NEP SYSTEM

FIRST NEP FLIGHT SYSTEMS	\$35.2M
SECOND FLIGHT NEP SYSTEM AT ~80 PERCENT	\$28.2M
SUBSEQUENT FLIGHT NEP SYSTEMS MAY APPROACH ~70 PERCENT	\$24.6M

PRODUCTION RATE OF ONE NEP SYSTEM PER YEAR REQUIRED TO ACHIEVE MINIMUM COSTS

NEP System start-up sequence is evaluated, including auxiliary power requirements.

AGENDA

- PROGRAM OVERVIEW
  - BACKGROUND
  - OBJECTIVES
  - KEY GUIDELINES AND CONSTRAINTS
  - APPROACH
  - SCHEDULE AND STATUS SUMMARY
- PROGRAM RESULTS
  - DEVELOPMENT COSTS
    - COMMON GUIDELINES
    - BASELINE PROGRAM
    - MINIMUM PROGRAM
  - RECURRING COSTS
    - LIQUID METAL HEAT REJECTION SUBSYSTEM
    - FLIGHT NEP SYSTEM ESTIMATES
  - MISSION OPERATIONS
    - ➧ NEP SYSTEM STARTUP
    - COMMUNICATIONS
- CONCLUSIONS - PHASE II
- PLANNED FUTURE EFFORT - PHASE III

The coordinated start-up and shut-down sequences of the thermionic NEP system were investigated in order to define an acceptable operation sequence, determine the size and weight of the required auxiliary power battery system, assess the impact of NEP system deployment by electric power on the auxiliary power system (APS) requirements, and to investigate NEP system restart characteristics.

The start-up sequence recognizes thermionic reactor start-up limitations and employs ion engine start-up characteristics established by JPL. Mission events do not require a hurried start-up; self-sustaining power for the power subsystem being attained over two hours after lift-off.

Although no need for complete shut-down of the power system is identified for outer planet exploration missions, such may be required for other missions, or may result from an inadvertent scram. The APS is sized to provide afterheat removal assuming equilibrium fission product inventories associated with thousands of full power hours operation.

SPACE DIVISION

NEP SYSTEM STARTUP

OBJECTIVES

- DEFINE COORDINATED STARTUP AND SHUTDOWN SEQUENCE
- DETERMINE SIZE AND WEIGHT OF BATTERY AUXILIARY POWER SYSTEM (APS)
- INVESTIGATE IMPACT OF ELECTRICAL NEP SYSTEM ON APS
- ASSESS UNIQUE NEP SYSTEM RESTART CHARACTERISTICS

KEY ASSUMPTIONS

- GULF GENERAL ATOMIC THERMIONIC REACTOR STARTUP LIMITS ARE IMPOSED
- JPL ION ENGINE STARTUP CHARACTERISTICS ARE IMPOSED
- NO SCHEDULED REACTOR SHUTDOWN - INADVERTANT SCRAM POSSIBLE
- AFTERHEAT BASED ON 1000 DAY EQUILIBRIUM FISSION PRODUCTS
- TIME SEQUENCE BASED ON NOMINAL LAUNCH PROFILE
- MISSION EVENTS DO NOT DICTATE HURRIED STARTUP

No electrical power is available from the reactor for use in the spacecraft until reactor start-up is completed (Step 4), a nominal two hours and 13 minutes after lift-off. Electrical power required during the time prior to Step 4 will have to be provided from other sources.

After lift-off, the shuttle ascent operations follow standard flight procedures. Shuttle-orbiter separation is followed by coast and then thrust to a circular parking orbit, during which time any necessary electrical power is being provided to the spacecraft by the shuttle electric power supply, not considered in this study. Then, following a successful completion of system checkout in the parking orbit, the spacecraft system is switched to the internal auxiliary power supply. Hereafter, all necessary electrical power is supplied from on-board, secondary, nickel-cadium batteries until the thermionic reactor is capable of assuming the load.

Next, the NEP Spacecraft/Centaur is separated from the orbiter, followed by Centaur stage boost into an Earth escape trajectory and then subsequent separation of the NEP system. Immediately following separation, deployment and latching of the NEP system is completed. Final checkout, before reactor start, is then performed on the NEP system, including the reactor control.

SPACE DIVISION

NEP SYSTEM STARTUP
TIME SEQUENCE SUMMARY BY MISSION PHASE

MISSION PHASE	TIME	POWER SOURCE
• PRELAUNCH OPERATIONS	10 HOURS	BLOCKHOUSE
• SHUTTLE ASCENT		ORBITER
LIFTOFF	0	
INITIAL THRUST	5 MINUTES	
COAST-INITIAL APOGEE	30 MINUTES	
ORBITER BURN	3 MINUTES	
COAST-CIRCULAR ORBIT	30 MINUTES	
ORBITER SEPARATION	0	
• EARTH ESCAPE, NEAR-EARTH OPERATIONS		
CENTAUR BURN	15 MINUTES	NEP BATTERIES
COAST-NEP DEPLOYMENT	10 MINUTES	
COAST-CHECKOUT	5 MINUTES	
REACTOR STARTUP	35 MINUTES*	
THRUSTER STARTUP	50 MINUTES	THERMIONIC REACTOR
• HELIOCENTRIC FLIGHT	MISSION DEPENDENT	THERMIONIC REACTOR
• PLANET/COMET ARRIVAL	MISSION DEPENDENT	THERMIONIC REACTOR

* 35 MINUTES FOR 200 WATT NET SPACECRAFT LOAD
35 MINUTES FOR 1000 WATT NET SPACECRAFT LOAD

The battery matrix shows the weight and volume associated with nickel-cadium batteries necessary to provide thermionic reactor start-up, deployment and coolant circulation for the NEP System.

In order to accommodate the arbitrarily assumed 200-watt Net Spacecraft load, and assuming an allowable 60 percent depth-of-discharge condition, approximately 613 watt-hours of battery capacity must be provided. For example, a 1,000-watt net spacecraft load, during NEP System start-up, the batteries must be sized for 2,106 watt-hours.

A total of 1,000 watts of power for ten minutes are allocated for NEP System deployment prior to start-up, requiring approximately 278 watt-hours of additional battery capacity. These batteries weigh about 14 kg, and may be discarded after NEP System deployment.

A low flow pump circulation will be necessary to minimize temperature variations within the coolant loop prior to reactor start-up. There is approximately 30 minutes after leaving the orbiter until the reactor start-up sequences is initiated, during which time cool-down takes place, with the potential of freezing. Allowing a 5 percent pump flow, approximately 10 watt-hours of battery energy are necessary for pre-start circulation.

Similar to pre-start, coolant must be circulated following reactor shut-down to prevent radiator freezing and to dissipate heat from the fission product decay. Near Earth, 400 watt-hours of energy are required, and 80 watt-hours are required in deep space.

Supplying 200 watts(e) to the Net Spacecraft, the total APS battery weight is about 50 kg, including a maximum of 18.1 kg for near Earth coolant circulation in the event of inadvertent shutdown, and 1.4 kg for the battery charge regulator, and 0.45 kg for pre-start circulation.

GE SPACE DIVISION

NEP SYSTEM STARTUP BATTERY MATRIX**

OPERATION	WEIGHT		VOLUME	
	KILOGRAMS	POUNDS	$METERS^3$	$INCHES^3$
• REACTOR STARTUP, INCLUDING 200 WATT NET SPACECRAFT LOAD*	29.5	65	0.0067	410.0
• REACTOR STARTUP, INCLUDING 1000 WATT NET SPACECRAFT LOAD*	95.3	210	0.0231	1410.0
• DEPLOYMENT	13.6	30	0.0030	185.0
• PRE-START CIRCULATION	0.45	1	0.0002	7.5
• SHUTDOWN CIRCULATION				
NEAR EARTH (38.9 HOURS)	18.1	40	0.0043	260.0
DEEP SPACE (7.8 HOURS)	3.6	8	0.0009	52.0
BATTERY CHARGE REGULATOR	1.4	3	0.0016	96.0

*NET SPACECRAFT LOAD OF 200 WATTS AND 1000 WATTS ARE ASSUMED ARBITRARY.
**NICKEL-CADMIUM CELL CONSTRUCTION.

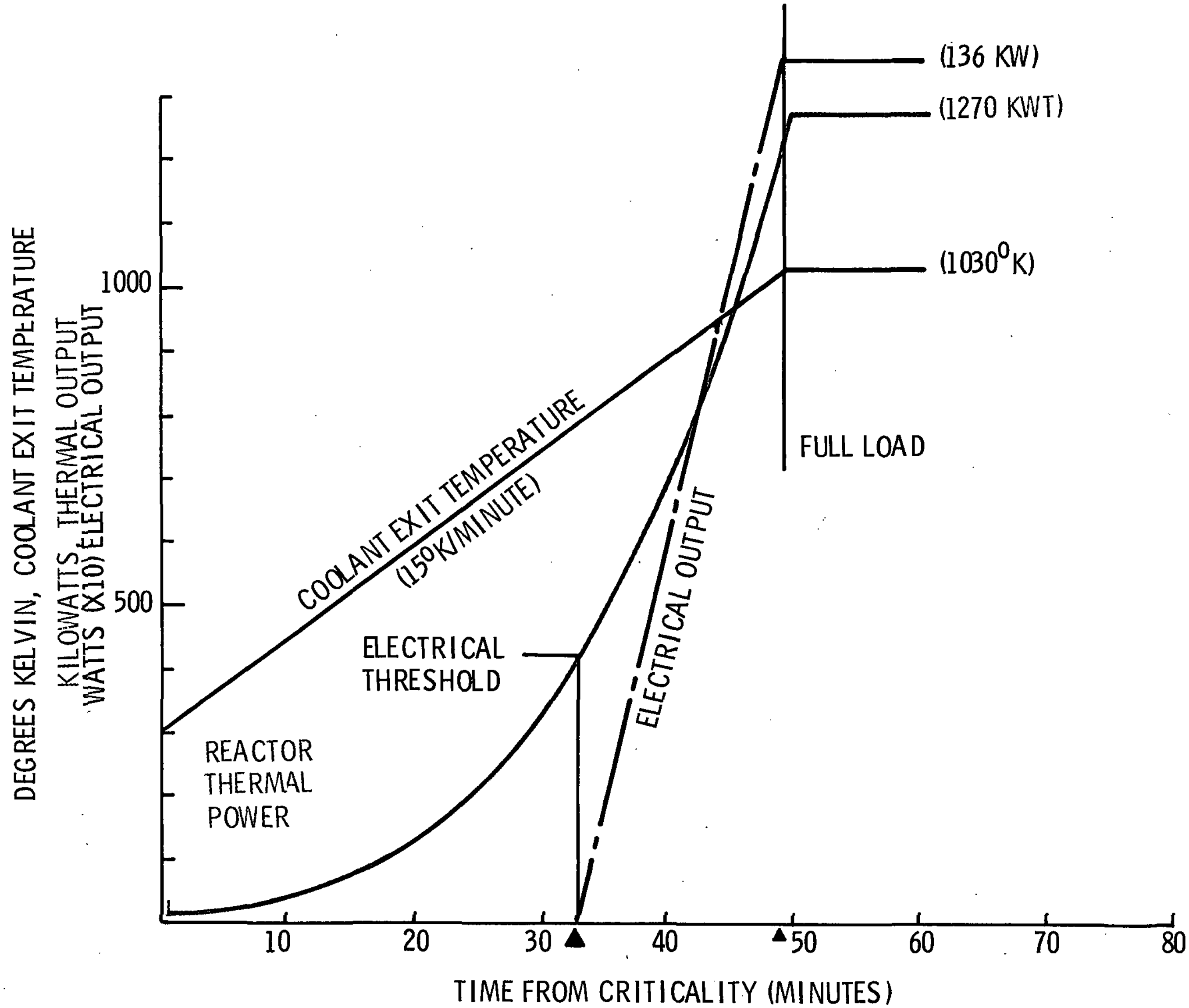
After checkout of the instrumentation and control, the thermionic reactor start-up is initiated by insertion of reactivity, until criticality is achieved. Thereafter, to control internal thermal stress, reactivity is inserted to increase the thermal power at a rate not to exceed an allowable rate of change in the coolant outlet temperature. As thermal power reaches approximately 30 percent of full-rating, electrical power becomes available as evident by the open circuit voltage rising to the operational level. A continuing increase in the reactor thermal power increases the available electrical power until full-load is reached.

For an initial coolant temperature of $300^{o}K$, the minimum time to the electrical threshold is about 30 minutes, and to full load is 35 minutes, observing the $15^{o}K$/minute* coolant exit temperature rate of change.

*supplied by GGA, GA-A 10535

SPACE DIVISION

STARTUP CHARACTERISTICS
40 VOLT FLASHLIGHT

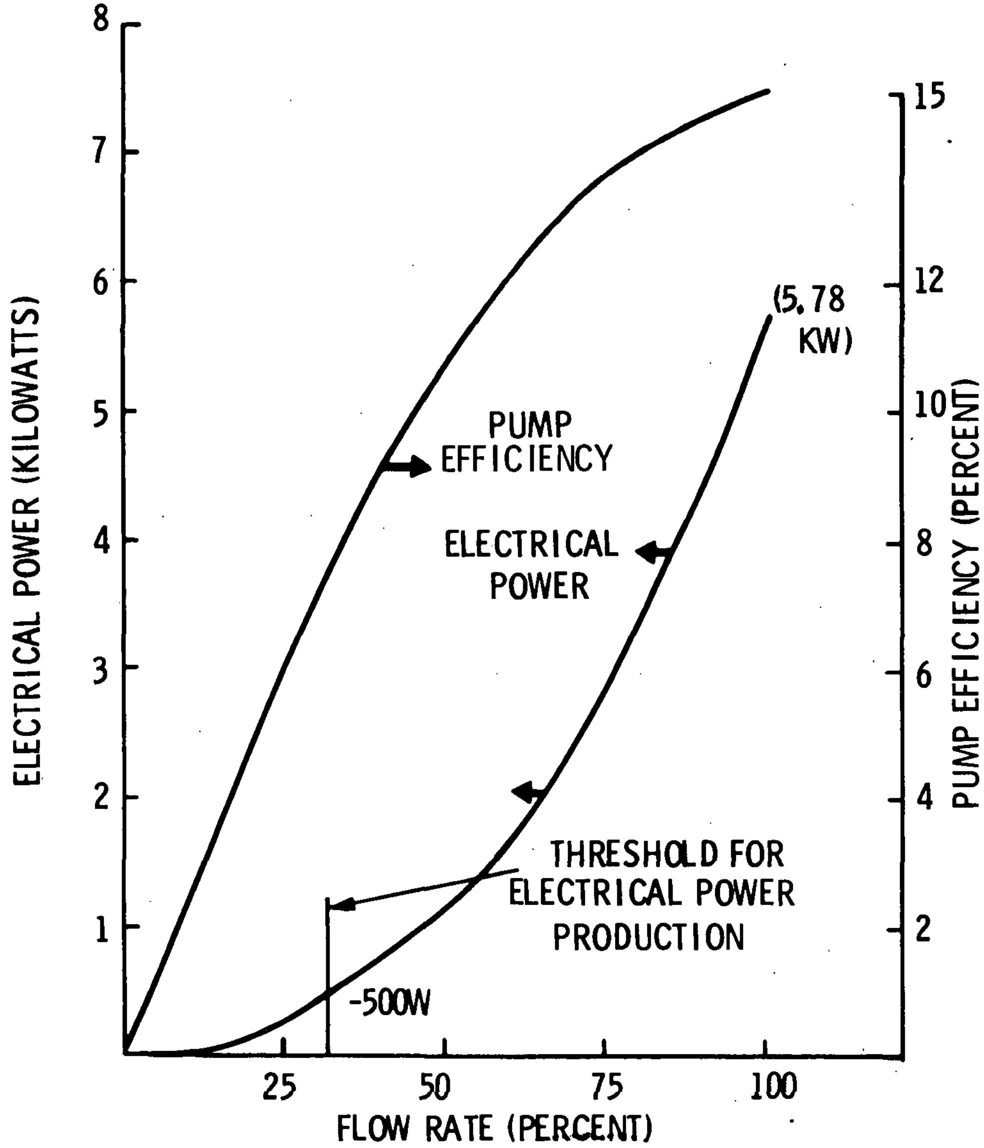


As the reactor thermal power level is increased during reactor start-up, the coolant flow is increased proportionally, maintaining a constant temperature differential across the reactor.

The relationship of the coolant electromagnetic pump electrical power and efficiency to flow rate are shown. The coolant pump electrical power is assumed to vary according to the function:

$$\text{Pump Electrical Power} \quad \frac{(\text{Flow})^{2.8}}{\text{Efficiency}}$$

COOLANT PUMP POWER REQUIREMENTS



On-board nickel-cadium batteries must supply the electrical power for the NEP system from the time of orbiter separation until the reactor can assume the load. The shaded area on the power profile plot shows the energy requirement for which the batteries are responsible.

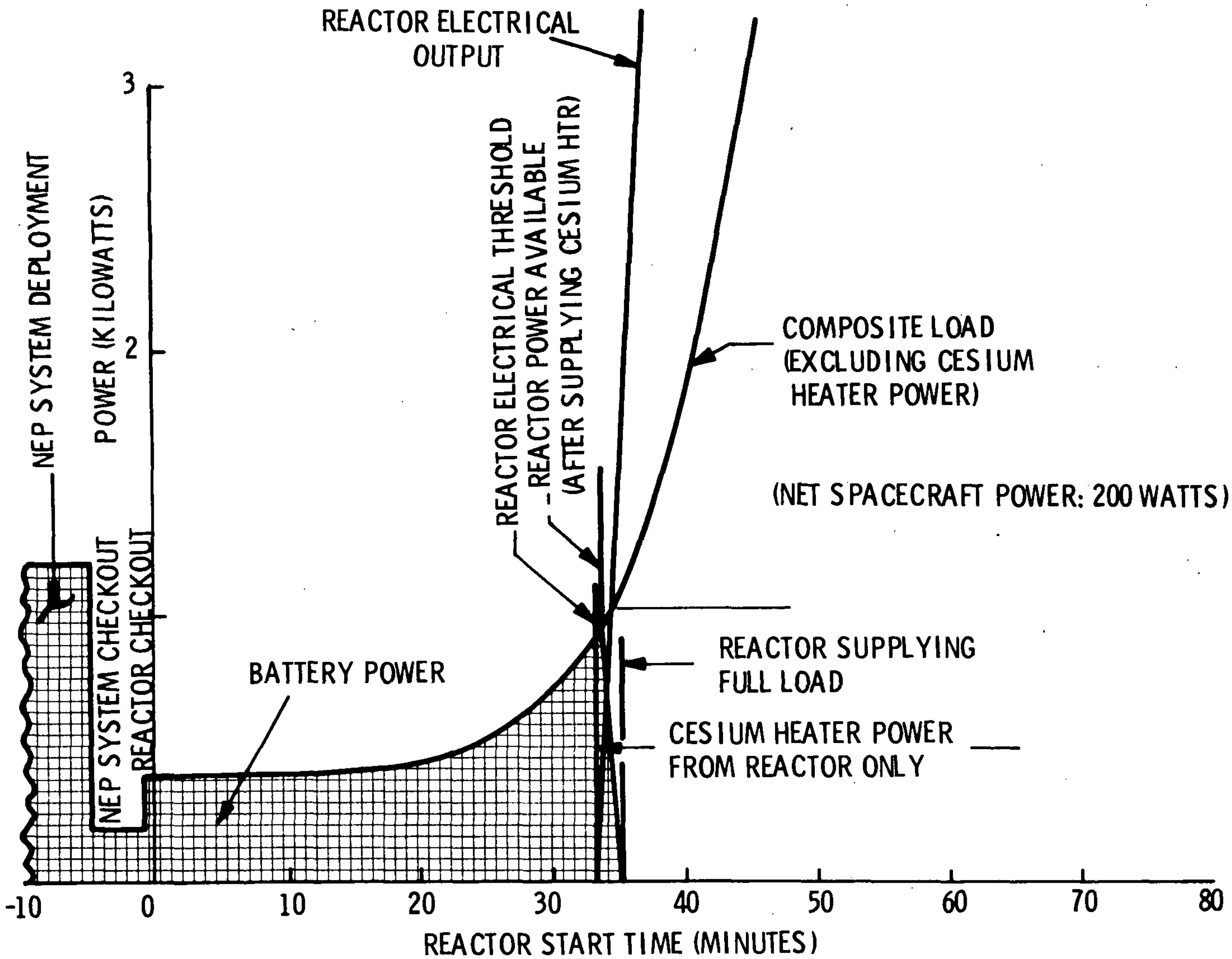
The electrical requirements prior to reactor start-up consists of a Net Spacecraft load for command, communication, and attitude control, and for the spacecraft deployment mechanism. After start-up, the load increases to include the coolant EM pump and the cesium heaters.

After start-up initiation, the coolant flow is increased proportionally to the reactor thermal power. Consequently, the composite electrical load increases with time. Once electrical threshold is achieved and the cesium heater load is supplied, the batteries are required to support less of the load until the reactor supplies the complete system demand.

It is seen from the power profile for an arbitrarily assumed 200-watt Net Spacecraft load, that the thermionic reactor is supplying the entire electrical load within 35 minutes after the start of the reactor.

SPACE DIVISION

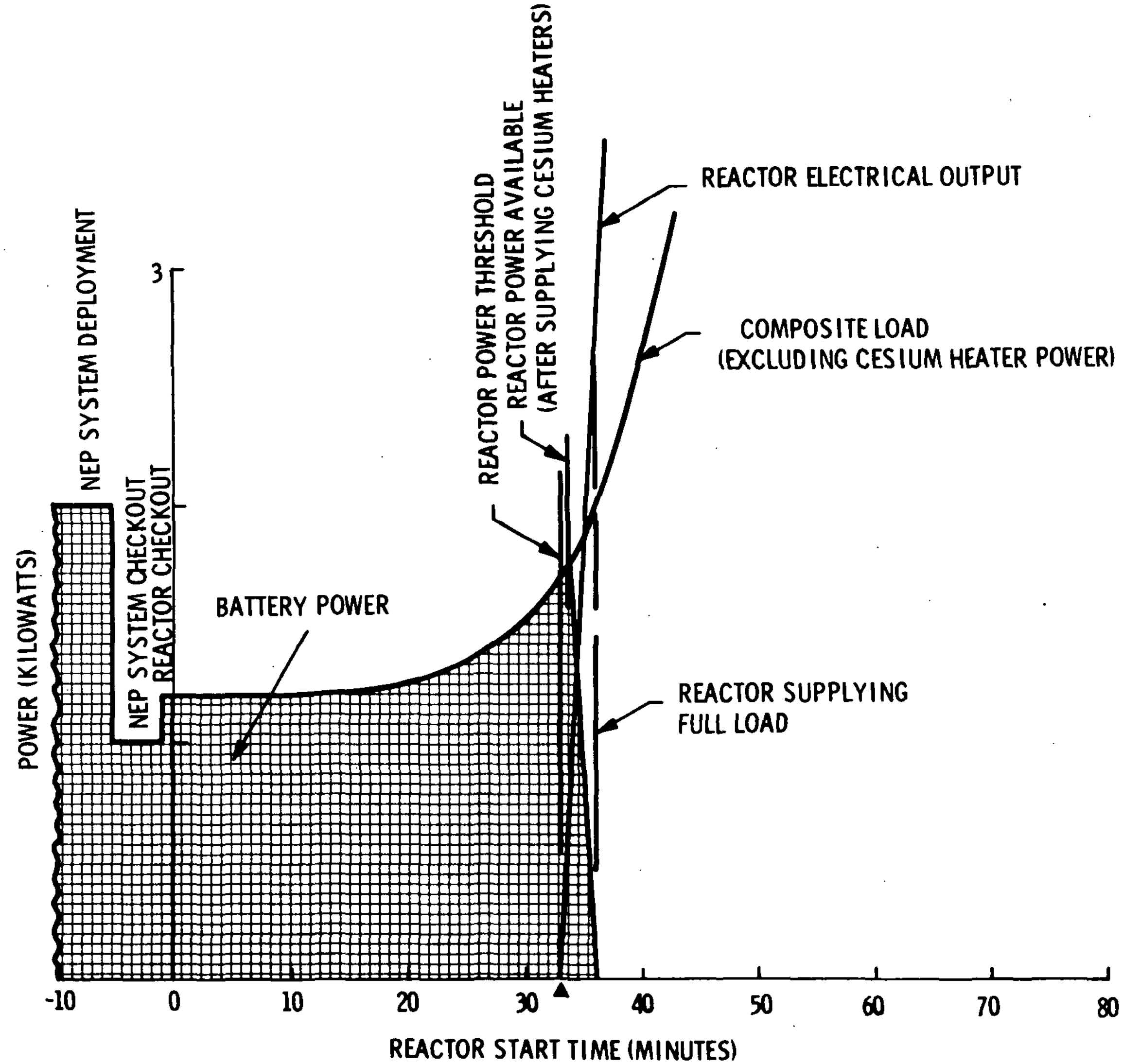
POWER PROFILE
REACTOR START SEQUENCE
(NET SPACECRAFT POWER: 200 WATTS)



For a spacecraft with an arbitrarily assumed 1,000-watt net power requirement, the start-up batteries no longer are required 36 minutes after initiation of reactor start.

SPACE DIVISION

POWER PROFILE
REACTOR START SEQUENCE
(NET SPACECRAFT POWER: 1000 WATTS)



AGENDA

- PROGRAM OVERVIEW
  - BACKGROUND
  - OBJECTIVES
  - KEY GUIDELINES AND CONSTRAINTS
  - APPROACH
  - SCHEDULE AND STATUS SUMMARY
- PROGRAM RESULTS
  - DEVELOPMENT COSTS
    - COMMON GUIDELINES
    - BASELINE PROGRAM
    - MINIMUM PROGRAM
  - RECURRING COSTS
    - LIQUID METAL HEAT REJECTION SUBSYSTEM
    - FLIGHT NEP SYSTEM ESTIMATES
  - MISSION OPERATIONS
    - NEP SYSTEM STARTUP
    - COMMUNICATIONS
- CONCLUSIONS - PHASE II
- PLANNED FUTURE EFFORT - PHASE III

The interplanetary missions planned for the NEP System require the transmission of large quantities of data over distances up to several billion kilometers. For a particular mission, the quantity of data which can be transmitted for a time-period is directly related to the transmitter radiated power and the data-coding efficiency. Therefore, arriving on target-rendezvous with the thermionic reactor electrical capacity no longer necessary for ion propulsion, the NEP system has a large communication capability using the available power.

The amount of radiated power necessary for communications is dependent upon receiving a signal with a minimum strength above the background noise to insure understanding the information. The type of data-coding dictates this minimum signal-to-noise ratio (SNR). Pioneer-65, for instance, used phase-shift keying (PSK) requiring approximately 8 db minimum SNR. Mariner-69 used block encoded biorthogonal comma-free code with a resulting improvement in SNR required, of approximately 2.2 db over PSK. An additional improvement in SNR of approximately 3.4 db is achieved in Pioneer-10 by using convolutional encoding in the space probe and sequential decoding at the receiver. Consequently, systems using convolutional encoding require approximately 1/4 the transmitted power of the conventional PSK system. The major disadvantages of convolutional encoding is the amount of computer equipment necessary for decoding and decoding time-delay.

The NEP System, with an arbitrarily assumed 15-foot diameter parabolic communication antenna, is capable of transmitting video at 10^6 bit/second rate from Jupiter, expending 16 kilowatts of electrical power for PSK coding and 4 kilowatts with convolutional encoding. High quality color video requires a data rate of 10^7 bits/second, which from Jupiter requires 40 kilowatts of power using convolutional encoding.

The frequency was assumed to be 3.2 GHZ (S-band), the NEP Spacecraft antenna is assumed to have a 38 db gain. The DSIF ground station is assumed, with a 61.4 db gain. The noise temperature is 30°K (DSIF) and the signal margin assumed is 6 db.

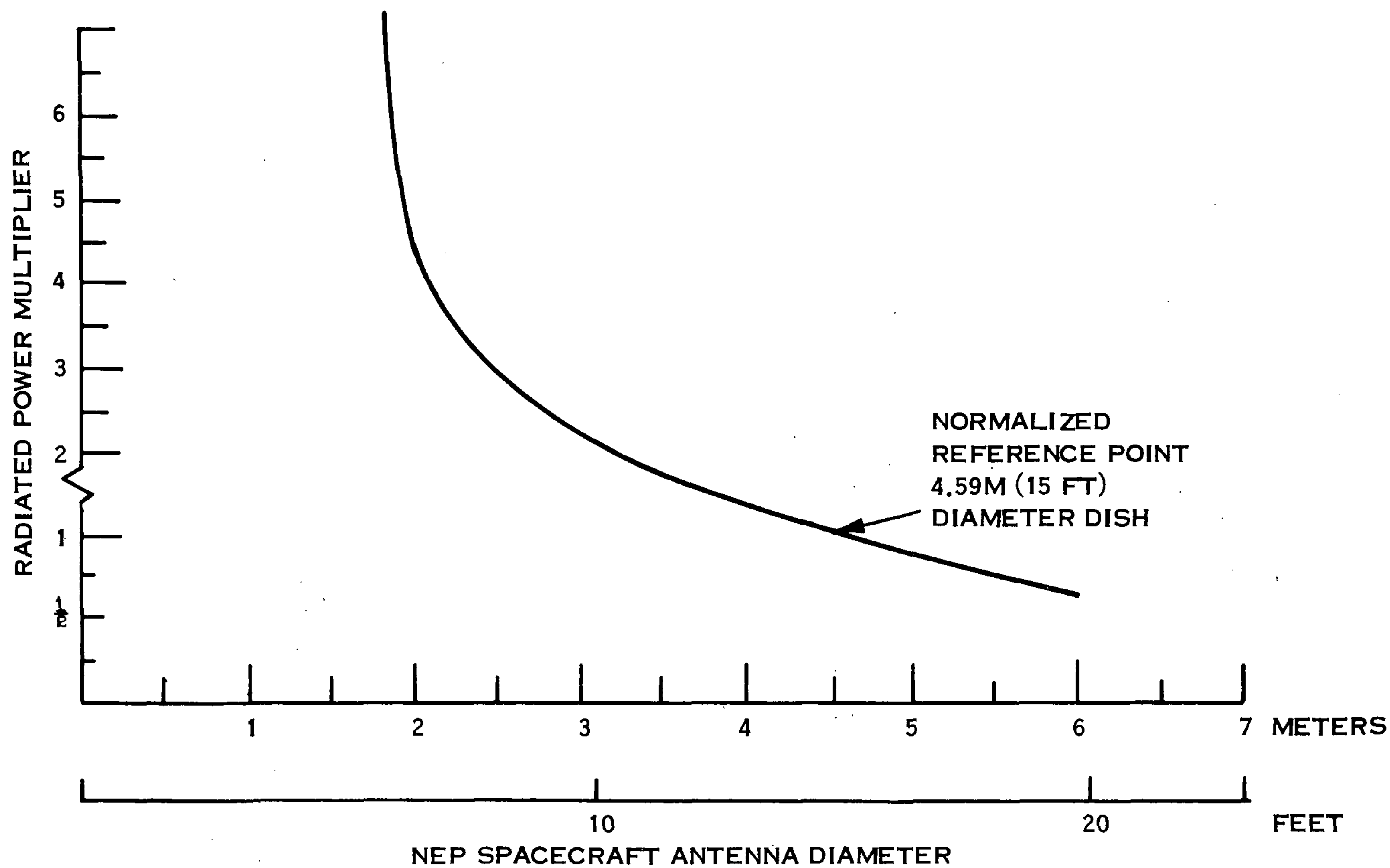
COMMUNICATION POWER REQUIREMENTS
LINK CALCULATION RESULTS

MISSION	BITS/SECOND 10^3	BITS/SECOND 10^6	PIONEER
MERCURY	0.1 WATTS	0.100 kW	
JUPITER	4	4	8W; 10^3 BPS
SATURN	5.5	5.5	9 FT. DIA. ANTENNA
URANUS	20	20	
NEPTUNE	48	48	
PLUTO	80	80	
ASTEROID	0.4	400	
SUN	166	166	

- DSN
- 15 FT. DIA. SPACECRAFT ANTENNA
- CONVOLUTIONAL ENCODING
- SEQUENTIAL DECODING

The multiplier is presented for radiated power when antenna sizes other than the assumed 15-foot parabolic dish are employed. Unless the antenna can extend outside the NEP system shadow shield, its diameter will be limited to about 1.2 m (4 feet). This would increase transmitter power requirements by a factor of about 16.

ANTENNA SIZE AFFECT UPON RADIATED POWER (3.2 GHz)



AGENDA

- PROGRAM OVERVIEW
  - BACKGROUND
  - OBJECTIVES
  - KEY GUIDELINES AND CONSTRAINTS
  - APPROACH
  - SCHEDULE AND STATUS SUMMARY
- PROGRAM RESULTS
  - DEVELOPMENT COSTS
    - COMMON GUIDELINES
    - BASELINE PROGRAM
    - MINIMUM PROGRAM
  - RECURRING COSTS
    - LIQUID METAL HEAT REJECTION SUBSYSTEM
    - FLIGHT NEP SYSTEM ESTIMATES
  - MISSION OPERATIONS
    - NEP SYSTEM STARTUP
    - COMMUNICATIONS
- CONCLUSIONS - PHASE II
- PLANNED FUTURE EFFORT - PHASE III

One of the study objectives is to define missions and spacecraft interactions with the launch vehicles, facilities and related equipment.

Work completed during Phase I in this area demonstrates that the side thrust spacecraft must be folded in two places in order to attach it to the Centaur D-1T and install the total package within the 18.3 meter long 4.6 meter diameter Shuttle payload bay.

It appears that a single net spacecraft system can be developed that can be used to perform all identified missions. Only minor variations in the science between the comet rendezvous missions and the planetary missions have been identified. Other net spacecraft components are constant for all missions.

A considerable amount of test equipment will be required in conjunction with propulsion system fabrication. A propulsion system assembly, checkout and storage facility should be available at KSC.

Phase II results in this area show that total GSE plus facility costs will be between 15 percent to 20 percent of total NEP System development costs. Contractor related mission support operations at about $2.0M are less than one percent of total NEP Program costs. Launch vehicle costs of about $25M, and NASA mission support costs are not included in program totals.

KEY CONCLUSIONS
PHASE I AND PHASE II

- DEFINE MISSION AND SPACECRAFT INTERACTIONS WITH THE EARTH LAUNCH VEHICLES, FACILITIES AND RELATED EQUIPMENT

- SHUTTLE INTEGRATION OF THE NEP SPACECRAFT INSTALLED ON THE CENTAUR D1-T REQUIRES A FOLDABLE SPACECRAFT
- MISSION HAS MINOR INFLUENCE ON NET SPACECRAFT
- SIGNIFICANT TEST EQUIPMENT WILL BE REQUIRED IN CON-JUNCTION WITH PROPULSION SYSTEM FABRICATION

- TOTAL GSE PLUS FACILITIES COSTS REQUIRED FOR NEP FLIGHT SYSTEM DEVELOPMENT ARE OF THE ORDER OF $60M

- LAUNCH SUPPORT OPERATIONS ARE LESS THAN ONE PERCENT OF TOTAL NEP SYSTEM DEVELOPMENT COSTS

A second study objective is the investigation and definition of all operational aspects of a thermionic nuclear electric propulsion spacecraft.

The mission operations evaluation completed in Phase I indicates that mission operations are essentially identical for both comet rendezvous and planetary exploration missions. One exception may be the deployment of an atmospheric probe for planetary missions.

Phase I mission analysis demonstrates that a single NEP Spacecraft design is capable of performing a large number of attractive missions, and that the Shuttle/Centaur launch vehicle provides superior mission performance relative to the Titan/Centaur.

The evaluation of NEP system start-up completed in Phase II demonstrates that no particular problems exist. The power system can be brought to self-sustaining power in about 35 minutes. About 50 kg of NiCd batteries are required for power system start-up. These also provide 200 watts(e) to the Net Spacecraft during this period. Subsequent thrust system start-up is straight forward and similar to solar electric procedures.

A brief assessment of outer planet exploration communications power requirements was completed. Only about 12 kWe power input is required to the transmitter to send 10^6 B/S from Jupiter, assuming a 4.57 m (15 feet) diameter antenna on the spacecraft and the DSN earth receiver system. This power level increases about a factor of 16 if the spacecraft antenna size is constrained to its current value of about 1.2 m (4 feet). The reduced power requirements associated with the larger antenna size recommend studies to evaluate the scattered radiation dose from the low density antenna to potentially sensitive electronics.

KEY CONCLUSIONS
PHASE I AND PHASE II

- INVESTIGATE AND DEFINE ALL OPERATIONAL ASPECTS OF A THERMIONIC NUCLEAR ELECTRIC PROPULSION SPACECRAFT

- MISSION OPERATIONS ARE ESSENTIALLY IDENTICAL FOR BOTH COMET RENDEZVOUS AND OUTER PLANET MISSIONS
- A MULTI-MISSION NEP SPACECRAFT IS FEASIBLE

- NEP SYSTEM STARTUP PRESENTS NO UNIQUE PROBLEMS
- NiCd BATTERY WEIGHT FOR STARTUP (AND RESTART) IS 50 kg
- NiCd BATTERIES ARE SELECTED TO MEET THREE YEAR LIFE REQUIREMENTS
- TRANSMISSION OF 10^6 B/S FROM JUPITER REQUIRES 12 kWe POWER INPUT TO TRANSMITTER (4.57 M DIAMETER ANTENNA)

A key study objective is the definition of gross NEP System development costs. Two development options were examined during Phase II, and several perturbations common to these options were evaluated.

The recommended program will cost on the order of $275M and will result in a 20,000 full power hour NEP System with high reliability and true multi-mission capability. This system would be available for launch in the early 1980's. This program employs two ground test reactors, both of which impact the design of the flight NEP System. Total reliance on a successful solar electric program could reduce these costs by about $15M. However, partial and full ion engine arrays, configured for the NEP system, are assumed to be tested in this program.

A minimum NEP System development program leading to the development of a 10,000 full power hour system for early 1980's application was costed at $233M. A tentative objective to constrain the budget to less than $10M/year through FY 1976 could not be met and still meet an early 1980's launch. Such a constraint could be met by extending the program duration.

Facility and GSE costs average 15 to 20 percent of total program costs, and must be incurred relatively early in the program.

NEP flight system recurring costs could approach about $25M per unit if built at a rate of one unit per year or more.

SPACE DIVISION

KEY CONCLUSIONS
PHASE II

DEFINE GROSS NEP SYSTEM DEVELOPMENT COSTS

- MINIMUM ACCEPTABLE PROGRAM (BASELINE) IS OF THE ORDER OF \$275M
- SUCCESSFUL SEP PROGRAM CAN BENEFIT NEP PROGRAM UP TO ~\$15M
- FACILITIES AND GROUND SUPPORT EQUIPMENT ARE REQUIRED EARLY ON ALL OPTIONS EVALUATED. THESE COSTS ARE ABOUT \$60M
- TOTAL FLIGHT SAFETY COSTS ARE ~\$8M
- RECURRING COSTS FOR FLIGHT NEP SYSTEMS COULD APPROACH \$25M
- EXTENSIVE USE OF BERYLLIUM STRUCTURE INCREASES PROGRAM COSTS UP TO \$20M

AGENDA

- PROGRAM OVERVIEW
  - BACKGROUND
  - OBJECTIVES
  - KEY GUIDELINES AND CONSTRAINTS
  - APPROACH
  - SCHEDULE AND STATUS SUMMARY
- PROGRAM RESULTS
  - DEVELOPMENT COSTS
    - COMMON GUIDELINES
    - BASELINE PROGRAM
    - MINIMUM PROGRAM
  - RECURRING COSTS
    - LIQUID METAL HEAT REJECTION SUBSYSTEM
    - FLIGHT NEP SYSTEM ESTIMATES
  - MISSION OPERATIONS
    - NEP SYSTEM STARTUP
    - COMMUNICATIONS
- CONCLUSIONS - PHASE II
- PLANNED FUTURE EFFORT - PHASE III

The preliminary design of the multi-mission NEP spacecraft will be completed during the final phase of the program. Also the impact of nuclear electric propulsion upon the space program, and upon particular technology requirements will be assessed. The latter may include areas such as long life requirements and communications.

The study report will be prepared during Phase III.

PLANNED FUTURE EFFORT
PHASE III

- DESIGN MULTI-MISSION SPACECRAFT - AUGUST 1972
- ESTABLISH IMPACT OF NUCLEAR ELECTRIC PROPULSION ON
  - SPACE PROGRAM
  - TECHNOLOGY REQUIREMENTS

  } SEPTEMBER 1972
- PREPARE FINAL REPORT - SEPTEMBER 1972
- PREPARE FINAL BRIEFING - OCTOBER 1972

GENERAL ELECTRIC

Space Division / Headquarters: Valley Forge, Pennsylvania □ Daytona Beach, Fla. □ Cape Kennedy, Fla. □ Evendale, Ohio □ Huntsville, Ala. □ Bay St. Louis, Miss. □ Houston, Texas □ Newport Beach, Calif.