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Volume I
SUMMARY

MASTER

**DYNAMIC ISOTOPE POWER SYSTEM (DIPS)
APPLICATIONS STUDY**

Final Report

November 1979

GENERAL ELECTRIC

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Prepared for

**DEPARTMENT OF ENERGY
DIVISION OF ADVANCED NUCLEAR SYSTEMS AND PROGRAMS**

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**GENERAL ELECTRIC
SPACE DIVISION
PHILADELPHIA, PA. 19101**

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REPORT ORGANIZATION

This report is presented in three volumes:

Volume I — Summary

Volume II — NIMS Design Definition

Volume III — NIMS Survivability Assessment

ADDITIONAL INFORMATION

Additional information that may be required regarding the work performed in this study may be obtained from the following personnel:

General Electric Company
Space Division

W. Z. Prickett, Program Manager
(513) 243-4136

R. T. Martin, Military Programs
(215) 962-3894

Department of Energy
Division of Advanced Nuclear Systems and Programs

D. Kenney
(301) 353-2995

TABLE OF CONTENTS

<u>Section</u>		<u>Page</u>
1	OBJECTIVES.	1-1
	1.1 DIPS Attributes Assessment	1-1
	1.2 NIMS Bus Requirement	1-1
	1.3 Utilization of Previous Work	1-3
2	RESULTS	2-1
	2.1 Survivability.	2-3
	2.1.1 Laser Threat.	2-3
	2.1.1.1 NIMS Response to the Laser Threat.	2-4
	2.1.1.2 Alternate Power System Survivability Technique.	2-9
	2.1.1.3 NIMS Maximizes Survivability at the SMATH IV Level	2-9
	2.1.2 JCS Nuclear Threat.	2-9
	2.2 Cost	2-13
	2.2.1 Cost Guidelines and Assumptions	2-14
	2.2.2 Cost Summary.	2-15
	2.2.3 Impact of Isotope Fuel Cost	2-19
	2.2.4 NIMS Cost/Benefits Assessment	2-21
	2.3 Multimission Applications.	2-22
	2.3.1 DMSP-NIMS Orbital Configuration	2-24
	2.3.2 NFCS-NIMS Orbital Configuration	2-24
	2.3.3 DSCS IV - NIMS Orbital Configuration.	2-27
	2.3.4 GPSCS - NIMS Orbital Configuration.	2-27
	2.3.5 GPS ØIII - NIMS Orbital Configuration	2-27
	2.3.6 DSSS - NIMS Orbital Configuration	2-27
	2.3.7 NIMS Alternate Missions Weight Summary.	2-28
	2.4 Reduced Mission Constraints.	2-28

TABLE OF CONTENTS (CONT'D)

<u>Section</u>	<u>Page</u>
2.4.1 Relaxation of Mission Constraints.	2-30
2.4.2 Mission Performance Improvements	2-30
2.5 NIMS/DIPS Schedules Compatible.	2-30
3 GUIDELINES	3-1
4 NUCLEAR INTEGRATED MULTI-MISSION SPACECRAFT (NIMS) DESCRIPTION	4-1
4.1 Spacecraft Systems Approach to Space Nuclear Power. . . .	4-1
4.1.1 Pumped Coolant Loop Utilization.	4-1
4.1.2 Payload/Electronics Integration.	4-3
4.1.3 Multimission Capability.	4-3
4.2 NIMS Configuration Selection.	4-3
4.3 NIMS Design Features.	4-6
4.4 NIMS-STs Vertical Installation.	4-8
4.5 Weight and Performance Summary (Synchronous Missions) . .	4-11
4.5.1 Performance.	4-11
4.5.2 Weight Breakdown	4-11
4.6 NIMS Assemble, Test and Launch Flow	4-13

LIST OF FIGURES

<u>Figure No.</u>		<u>Page</u>
2.1-1	Threat Scenario	2-5
2.1-2	NIMS Maximizes Survivability Against Threat	2-7
2.1-3	NIMS Design Maximizes Electronics and Power System Survival	2-8
2.1-4	System Survivability Options	2-10
2.2-1	Impact of Pu-238 Fuel Cost on NIMS Bus Unit Cost for Flight Systems	2-20
2.2-2	Enhanced Laser Survivability is Achievable with Nuclear Power at Moderately Increased Cost	2-23
2.3-1	DMSP-NIMS Orbital Configuration	2-25
2.3-2	Multimission Applicability Established	2-26
2.4-1	NIMS Reduces Mission Constraints Relative to Solar Array/Battery Systems	2-31
2.5-1	Possible Dynamic Isotope Power System Program Compatible with Mid-80's DOD Missions	2-32
4.1-1	Spacecraft Systems Approach to Space Nuclear Power . .	4-2
4.2-1	NIMS General Arrangement	4-4
4.3-1	NIMS Features	4-7
4.3-2	NIMS Exploded View	4-9
4.4-1	NIMS-STV Vertical Installation	4-10
4.6-1	NIMS Parallel Assembly and Test Flow	4-15

LIST OF TABLES

<u>Table No.</u>		<u>Page</u>
1-1	Overall Objectives & Requirements	1-2
2.1	Summary of Results	2-2
2.1-1	Candidate Solar Array/Battery Survivability Techniques	2-11
2.1-2	JCS Threat Assessment	2-12
2.2-1	NIMS and SAB Bus Development Cost Through Qualification are Equal Except for DIPS Development	2-16
2.2-2	NIMS and SAB Bus Unit Cost Summary	2-17
2.3-1	NIMS Alternate Missions Weight Summary	2-29
3-1	Guidelines for NIMS Bus Definition	3-2
4.5-1	NIMS Weight Summary - Synchronous Missions	4-12

SECTION 1

OBJECTIVES

The study objectives and requirements, summarized in Table 1-1, are discussed.

1.1 DIPS ATTRIBUTES ASSESSMENT

The baseline objective is to assess the attributes of the Dynamic Iso-tope Power System (DIPS) when it is thermally integrated with a spacecraft bus. This assessment addresses all identified DOD missions for which the DIPS may have potential application during approximately the next ten years. Its scope includes operational advantages and disadvantages relative to solar array/battery powered spacecraft.

The scope of the economic assessment covers the development (through qualification) and unit costs of the spacecraft bus. No payload costs are considered. Rough-order-of-magnitude (ROM) costs are delineated and compared for:

- 1) The Nuclear Integration Multimission Spacecraft (NIMS) Bus which has enhanced survivability and extended mission life in natural and hostile man-made space environments.
- 2) An unenhanced Solar Array/Battery (SAB) powered spacecraft bus.

No rigorous comparison with the solar array/battery powered bus is possible at this time because comparable data is not currently available.

1.2 NIMS BUS REQUIREMENT

The definition of a Nuclear Integrated Multimission Spacecraft (NIMS)

TABLE 1-1. OVERALL OBJECTIVES & REQUIREMENTS

- **ASSESS THE ATTRIBUTES OF DIPS AS THE SPACECRAFT POWER SUBSYSTEM FOR ALL IDENTIFIED DOD MISSIONS**
 - **OPERATIONAL ADVANTAGES AND DISADVANTAGES**
 - **ECONOMICS**
- **DEFINE AN INTEGRATED NUCLEAR SPACECRAFT BUS WITH MULTI-MISSION CAPABILITY TO FACILITATE THIS ASSESSMENT**
 - **COMMUNICATIONS (NFCS, GPSCS, DSCS IV)**
 - **SURVEILLANCE (DSSS)**
 - **NAVIGATION (GPS Ø III)**
 - **METEROLOGICAL (DMSP)**
- **MAXIMUM USE OF PREVIOUS WORK**
 - **DEVELOPED HARDENED SPACECRAFT HARDWARE/ TECHNIQUES**
 - **NUCLEAR GPS S/C STUDY**

Bus is necessary to support the baseline objective. The NIMS Bus must be compatible with any of the payloads required by the candidate missions assessed. This includes communications, surveillance, navigation and meteorological missions.

1.3 UTILIZATION OF PREVIOUS WORK

The study utilizes earlier related work to the greatest possible extent. The DIPS thermal integration approach is based on an earlier study which investigated the Global Positioning Satellite (GPS) mission at the stage of its Phase I development.* In addition, developed or evolving hardened spacecraft hardware and design techniques are identified. Key subsystem designs are based on flight hardware developed at GE Space Division for missions such as NIMBUS, LANDSAT, BSE and DSCS III. Data on subsystems such as attitude control, tracking telemetry and control, propulsion, thermal control, and structure are utilized in the definition of the NIMS Bus and its cost, as well as the Solar Array/Battery(SAB) Bus costs. Solar array/battery electrical power system data from these programs are used to assist in defining SAB Bus costs. The Dynamic Isotope Power System (DIPS) costs are provided by the DOE from their contractor, Sundstrand Energy Systems.

* Nuclear-Powered GPS Spacecraft Design Study, Fairchild Space & Electronics Company, ERDA NRA 3063 10, May 1977

SECTION 2

RESULTS

This section summarizes the study results. The attributes of survivability, cost, multimission applicability and reduced mission constraints are discussed. Analyses and discussion supporting these results are presented in NIMS Design Definition, Volume II of this report, except for survivability, which is discussed in Volume III, NIMS Survivability.

The salient study results summarized in Table 2-1 are:

- The ability of the DIPS, as integrated in the NIMS, to maximize survivability from the SMATH IV threat level with minimum impact on mission operations.
- The unit costs of the survivability enhanced NIMS Bus are about 11 percent (\$1.5 million) greater than an unenhanced solar array/battery powered bus. (Plus isotope costs.)
- The relaxed mission operation constraints afforded by the NIMS concept.
- The compatibility of the possible DIPS schedule with candidate DOD missions.

In addition, the NIMS Bus is fully applicable to all of the six DOD missions assessed. The weight of the survivability enhanced DIPS is comparable or superior to that of unenhanced solar array/battery systems.

The development cost of the survivability enhanced NIMS Bus (through qual) are about the same as that required to develop an unenhanced

Table 2.1 Summary of Results

- NIMS will provide enhanced survivability to the laser threat for spacecraft, payload electronics, and power supply.
- NIMS is fully applicable to all of the six DOD missions assessed.
- NIMS unit cost at \$14.7 million (plus isotope fuel) is only 11 percent greater than that of an unenhanced Solar Array/Battery (SAB) powered bus.
- NIMS development cost essentially equals to that of an unenhanced SAB Bus. The differential development cost of about \$16 million is the development cost for the Dynamic Isotope Power System (DIPS).
- NIMS development costs per mission, including laser survivability enhancement, are substantially less (30 to 75 percent) than those for an unenhanced SAB Bus, when the NIMS is used for more than one mission.
- At least three different SAB Bus units would have to be developed to perform all six DOD missions assessed:
 - One for the four Communications/Navigation missions
 - One for DMSP
 - One for DSSS
- Other NIMS attributes result in relaxed mission constraints.
- DIPS development schedule compatible with all missions evaluated.
- The hardened DIPS is over 100 lbs. lighter (20 percent) than an unenhanced solar array/battery system for DMSP
 - Weights comparable to unenhanced solar/battery systems for other missions.

solar array/battery powered bus, except for the DIPS development cost, which adds about 18 percent (\$16 million). However, when spread over the six missions studied, the total NIMS development cost may be less than half that of the several SAB Bus development costs required to perform the same six missions.

2.1 SURVIVABILITY

This paragraph summarizes the results of the assessment of the NIMS response to laser and nuclear threats. Details are presented in Volume III, NIMS Survivability Assessment.

2.1.1 LASER THREAT

The NIMS response to the laser threat up through the SMATH IV level has been assessed. Identified solar array/battery power system survivability techniques are briefly discussed. The NIMS concept provides enhanced survivability to the laser threat at the SMATH IV level, relative to solar array/battery powered spacecraft.

The key to the NIMS enhanced survivability to the laser threat is the integration of the Dynamic Isotope Power System such that cooling is provided for payload and housekeeping electronics. This feature is detailed in Paragraph 6.3, Volume II of this report, and is further discussed in Paragraph 4.1 of this volume. Basically, utilization of the DIPS pumped coolant loop permits thermal energy management capability to be incorporated into the NIMS design. The incident thermal energy absorbed is managed by a combination of the following NIMS features. A portion of this energy is:

- 1) Circulated to the non-illuminated side of the spacecraft by the pumped coolant, and re-radiated to cold space.
- 2) Absorbed in the DIPS components and structure, and then removed after threat encounter via the pumped coolant loop and rejected to space.

- 3) Prevented from reaching the payload and housekeeping electronics in significant amounts by using heat pipes, with their inherent thermal lag, to passively couple the electronics to the pumped coolant loop.

In addition, the isotope powered NIMS permits selection of the most favorable spacecraft orientation without regard for considerations such as power generation by solar arrays. This, together with the use of selective optical coatings, minimizes the fraction of the incident energy absorbed by the NIMS.

2.1.1.1 Nims Response to the Laser Threat

The two extremes for the NIMS encounter with the SMATH IV threat are illustrated on Figure 2.1-1. The best case occurs in the event of a direct overhead pass (zero azimuth). The NIMS radiator is fully shadowed from the peak flux which occurs directly over the source.

As the azimuth angle increases, one side of the NIMS cylindrical radiator becomes fully illuminated. However, increased range and atmospheric blooming act to decrease the arriving incident energy. As the azimuth angle approaches 90°, the incident flux again approaches zero. Analysis predicts that the incident energy on the NIMS radiator for the worst case is 25 to 30 percent of that which is encountered at the base of the NIMS for the overhead pass (zero degree azimuth). Full, 100 percent illumination of the 12 foot x 6.3 foot projected area of the NIMS radiator is assumed.

This geometry effect reduces the thermal load on the NIMS thermal control system. However, payload elements located at the base (earth facing) of the NIMS, such as antennas and special sensors must be separately hardened. This requirement exists for either nuclear or solar array battery powered spacecraft.

The DIPS can absorb over 15 percent of the peak energy incident of the total NIMS radiator (DIPS plus electronics cooling) in a low altitude encounter and survive to deliver full output power.

Figure 2.1-1. Threat Scenario

Figure 2.1-2 illustrates that up to five percent can be absorbed before the high thermal dissipator electronics such as TWT units exceed their normal operating temperature limit of 64°C ; up to 14 percent can be absorbed before the qualifications temperature limit of 85°C . Data are shown for 1) an uncooled thin metal surface representative of a conventional spacecraft, 2) the maximum temperature on the NIMS radiator shell, located between two radiator coolant tubes, 3) the maximum coolant temperature at the radiator exit (the sink temperature for payload cooling, minimum), and 4) TWT electronics units cooled via the pumped coolant loop. Further details are presented in Volume II. All data are for the worst case azimuth encounter.

These electronic components are typically mounted on north or south cold space facing panels in conventional solar array/battery powered spacecraft. As shown, such uncooled panels, even with threat reflective coatings, reach temperatures above the qual limit if over two percent of the energy is absorbed, and exceed 300°F (192°C) solder melting temperatures if over four percent of the energy is absorbed. If development of solar arrays with SMATH IV threat survival capability, the same as DIPS, were to be accomplished, it could permit the use of an electric motor driven pumped coolant loop which may provide the same electronics cooling capability as NIMS. However, only the DIPS technology is now ready for flight verification and use.

Typical temperature-time transient responses are presented on Figure 2.1-3 for electronic components mounted in a conventional spacecraft (north or south panel) and for similar components thermally integrated in the NIMS. These data complements that of Figure 2.1-2, presenting the total transient response for a five percent energy absorption.

The transient response presented on Figure 2.1-3 illustrates the degree of electronics protection and survival afforded by the NIMS, relative to conventional solar array/battery powered spacecraft. The high thermal dissipator TWT unit barely exceeds normal operating temperature limits for two or three minutes when installed in the NIMS. Conventional uncooled installation results in failure.

Figure 2.1-2. NIMS Maximizes Survivability Against Threat

Figure 2.1-3. NIMS Design Maximizes Electronics and Power System Survival

2.1.1.2 Alternative Power System Survivability Techniques

Numerous concepts for protection of electrical power and distribution subsystems employing solar arrays have been studied and some data has been collected on subscale hardware at intensities up to the SMATH I level. These concepts presented on Table 2.1-1 rely on reflection of a large percentage of the incident energy, physical orientation of the array to reduce the effective flux falling on the array surfaces. While each of these concepts has the potential to provide the needed protection at SMATH I levels, a combination of one or more of the reflective concepts with preferential orientation or the barrier approach is needed for larger fluxes. The impacts on vehicle materials, configuration, and mission operations are likely to be so large that the responsible system program office will show little interest in implementation of the concepts.

2.1.1.3 NIMS Maximizes Survivability at the SMATH IV Level

Mission survival from the SMATH IV level laser threat is maximized by the use of the NIMS concept. Alternate techniques are available to meet the lower SMATH threat levels, as shown on Figure 2.1-4. The DIPS power system and its integrated active cooling loop enhances on-board system and electronics survival. The NIMS concept minimizes interference with mission operations during threat encounter. There is no need to require full or partial disabling actions during threat encounter such as:

1. Rotating solar arrays
2. Shutdown of electronics
3. Evasive spacecraft maneuvers
4. Large mechanical moving systems such as deployable shields or shrouds.

2.1.2 JCS NUCLEAR THREAT

A requirement for all spacecraft support subsystems to meet the JCS threat was imposed on the NIMS Bus as shown on Table 2.1-2. These include items such as the power supply (DIPS), ACS, TT&C, and other housekeeping subsystems. The JCS hardened capability is provided

Figure 2.1-4. System Survivability Options

TABLE 2.1-1 CANDIDATE SOLAR ARRAY/BATTERY SURVIVABILITY
TECHNIQUES

CONCEPT	ADVANTAGE	DISADVANTAGE
DIELECTRIC STACK RESONANT REFLECTOR COVERGLASS	NEAREST TERM SOLUTION SOA TECHNOLOGY	MANUFACTURABILITY, ENVIRON- MENTAL STABILITY, WAVELENGTH SENSITIVITY, ANGULAR SENSITIVITY, ARRAY SIZE INCREASE, FLUX LIMIT- TATIONS
INTRINSIC REFLECTIVE CERAMIC COVERGLASS	ENVIRONMENTAL STABILITY, MULTIPLE WAVELENGTH CAPABILITY	MANUFACTURABILITY, ARRAY SIZE INCREASE, FLUX LIMITATIONS
ARRAY ORIENTATION CONTROL	MINIMIZES HARDENING REQUIREMENTS	POSSIBLE CONFLICT WITH MISSION REQUIREMENTS, INCREASED SOFTWARE COMPLEXITY, SUBJECT TO SURPRISE ATTACKS
DEPLOYABLE SHIELDS OR SHROUDS	GOOD POTENTIAL FOR IN- CREASED FLUX CAPABILITIES	SIGNIFICANT IMPACT ON MISSION OPERATIONS, INCREASED WEIGHT AND VOLUME, DEPLOYMENT MECHANISM RELIABILITY, COMMAND AND CONTROL COMPLEXITY

TABLE 2.1-2 JCS THREAT ASSESSMENT

REQUIREMENTS	AREAS OF CONCERN	ASSESSMENT
<ul style="list-style-type: none"> • NO ORIGINAL REQUIREMENTS • JCS IMPOSED FOR NIMS 	<ul style="list-style-type: none"> • DIPS ELECTRONIC CONTROLLER 	<ul style="list-style-type: none"> • USE DSCS III HARDENING TECHNIQUES/COMPONENTS
	<ul style="list-style-type: none"> • DIPS WORKING FLUID 	<ul style="list-style-type: none"> • NO PROBLEMS IDENTIFIED
<ul style="list-style-type: none"> • JCS IMPOSED FOR NIMS 	<ul style="list-style-type: none"> • SPACECRAFT SUPPORT SYSTEMS 	<ul style="list-style-type: none"> • USE DSCS III HARDENING TECHNIQUES/COMPONENTS

by using components and subsystems now being built for on-going DOD spacecraft programs. The DIPS was separately assessed.

No survivability requirements are imposed in the current DIPS development program being conducted for DOE by Sundstrand Energy Systems. However, only two areas of concern are identified for the DIPS relative to the JCS threat; the electronic controller and the organic working fluid, Dowtherm A. These system elements were assessed relative to the threat and no problems were identified. The JCS threat has little or no effect on the Dowtherm A. The electronics controller can be readily designed to meet the JCS threat using design techniques and component parts selection similar to those employed for other DOD spacecraft programs.

2.2 COST

This paragraph presents the results of the cost assessment completed in this study. Cost data are summarized for the development (through qualification) and flight system unit costs for:

- 1) The NIMS Bus with enhanced survivability from both natural and man-made hostile space environments.
- 2) An unenhanced SAB Bus.

No rigorous comparison with the SAB Bus is possible at this time because comparable data is not currently available for the SAB Bus.

No payload costs are included in the data presented.

The impact of isotope fuel costs on the NIMS Bus unit costs is summarized. The cost of the NIMS Bus is presented in terms of the enhanced survival benefit, relative to the SAB Bus.

The cost basis for these results is detailed in Section 8, Volume II of this report.

2.2.1 Cost Guidelines and Assumptions

This paragraph presents the guidelines and assumptions that are particular to the cost assessment performed for this study.

The major guidelines employed are:

1. Maximum use is made of applicable cost data available at General Electric Space Division from recently completed and on-going spacecraft. Programs such as NIMBUS, LANDSAT, BSE and DSCS III. These data are identified to define the development and unit costs for functional operations such as systems engineering, integration and assembly, test and evaluation, software, and program management. Specific subsystem costs such as the ACS, TT&C, thermal control, propulsion, electrical power, and structure are also derived from this data base, as applicable to either the NIMS or solar array/battery powered spacecraft bus.
2. The Dynamic Isotope Power System (DIPS) cost, except for the radiator and its optical cover, are based on data supplied by Sundstrand Energy Systems.
3. Component or subsystem costs that are particular to the NIMS Bus, such as the radiator and the thermal control system are generated from recent engineering estimates. Maximum use is made of previous related work.
4. Costs of shared components are pro-rated. The prime example is the NIMS radiator which is utilized by both the DIPS and the NIMS thermal control systems.
5. Isotope fuel (Pu-238) costs are treated parametrically. These data are presented in Section 8, Volume II of this report. The actual fuel costs would be determined by separate negotiations between the Department of Energy and the user agency.

The key assumptions employed in this cost assessment are:

1. No payload costs are included for any mission.
2. All estimates are in 1979 dollars.
3. Total dollar costs only are presented. There is no separate identification of material and labor costs.
4. An eight (8) percent fee is included in the summary costs.
5. No potential subcontractors are delineated, nor is any related additional G&A and fee included.
6. Unit costs assume a production rate of two-to-four units per year.

2.2.2 COST SUMMARY

The development costs, through the qualification unit, are summarized and compared on Table 2.2-1 for the NIMS Bus and a SAB Bus. The NIMS costs are consistent with the system guidelines and specifications presented in Section 3. A similar comparison is presented on Table 2.2-2 for the unit costs of the bus flight units. Although shown side by side, these costs are not directly comparable since the SAB Bus does not provide enhanced survivability against the laser threat.

The NIMS Bus development costs are estimated at \$80.34 million. The NIMS Bus development costs include an estimated \$16 million for the development of the DIPS, the major element in the NIMS Electrical Power Subsystem. Assuming that the DIPS is developed separately, the development cost of the two buses is approximately equal, as shown in Table 2.2-1.

The NIMS Bus will perform all of the six DOD missions investigated. Therefore, its use for more than one mission will substantially reduce its effective development cost per mission. For example, the NIMS effective develop-

Table 2.2-1 NIMS and SAB Bus Development Cost Through Qualification are
Equal Except for DIPS Development

<u>COST ELEMENT</u>	<u>\$ THOUSANDS</u>	
	<u>NIMS BUS</u>	<u>SAB BUS</u>
Subsystems		
Attitude Control	6,500	6,500
Tracking, Telemetry and Control	6,800	6,800
Thermal Control	2,290	1,700
Propulsion	4,000	4,000
Electrical Power	18,000	5,300
Structure	4,800	5,400
Systems Engineering	12,000	12,000
Integrator, Assembly and Support	1,600	1,600
Mechanical Support Equipment	200	200
Test and Evaluation	4,000	3,600
Communications Subsystem Simulator	700	700
Ground Command and Control Equipment	1,700	1,700
Command and Communications Software	3,400	3,400
Launch and Orbital Operations Services	1,200	1,200
Program Management	<u>6,800</u>	<u>6,800</u>
Total Bus	74,390	60,900
Development Cost Through		
Qualification		
Fee @ 8%	5,950	4,900
Selling Price	80,340	65,800
Selling Price Comparison w/o DIPS Development Costs	64,140	65,800

Table 2.2-2 NIMS and SAB Bus Unit Cost Summary

		\$ Thousands	
<u>COST ELEMENT</u>		<u>NIMS BUS</u>	<u>SAB BUS</u>
Subsystem			
Attitude Control		1,100	1,100
Tracking, Telemetry and Control		1,200	1,200
Thermal Control		690	300
Propulsion		2,000	2,000
Electrical Power		2,250*	1,150**
Structure		560	710
Systems Engineering		850	850
Integration, Assembly and Support		1,100	1,100
Test and Evaluation		1,500	1,420
Launch and Orbital Operations Services		570	570
Program Management		<u>1,800</u>	<u>1,800</u>
Total Bus Unit Cost		13,620	12,200
Fee @ 8%		1,090	980
Selling Price		14,710	13,180

* Plus isotope fuel

** Same EOM power level, 10 year life, synchronous orbit

ment cost becomes \$40 million if used for two missions; \$13.3 million if used for six missions. This includes the laser survivability enhancement capability. These values are substantially less than the \$65.8 million for the SAB Bus which does not provide enhanced survivability.

It may be possible to develop a single SAB Bus to serve the three communications missions and the GPS mission. However, a separate SAB Bus development will be required for each of the DMSP and the DSSS missions. The total SAB Bus development costs to perform all six missions is then about \$197 million (3 X \$65.8 million). And no laser survivability enhancement is provided.

The development of a single NIMS Bus will serve all six missions at a non-recurring cost of \$80 million, including DIPS. Laser survivability enhancement is provided.

The SAB Bus development costs of \$65.8 million does not include development costs necessary to assure the SAB Bus laser threat survivability enhancement. The additional costs necessary to provide the same SAB Bus survivability against the laser threat, assuming that it is technically feasible, is not available at this time.

The NIMS Bus unit costs are estimated at \$14.71 million, including about \$700,000 for the optional covers and \$270,000 for the special thermal control system which combine to provide the enhanced NIMS laser survivability at the SMATH IV level. The isotope fuel cost is not included. This cost element is treated parametrically in Paragraph 2.2.3, below. The SAB Bus unit costs, without laser survivability, are estimated at \$13.18 million. Both bus unit costs assume a low production rate of two-to-four units per year. No costs are included for any payload.

Key items that differ from the NIMS Bus unit costs are:

- 1) The Thermal Control System (TCS) is less expensive, \$300,000 vs. \$687,000. However, the SAB does not provide an integrated

payload TCS, and does not include enhanced laser survivability.

- 2) The Electrical Power System (EPS) is less expensive, \$1,500,000 vs. \$2,247,000. plus fuel. The SAB EPS does not include enhanced laser survivability.
- 3) The structure is slightly more expensive, \$710,000 vs. \$560,000 because of the solar array related structural items normally carried in this account.

Most of the other hardware cost elements are estimated to be the same for either the NIMS or the SAB Bus.

This cost analysis does not include an assessment of system level cost advantages provided by NIMS as identified in Paragraph 2.4 of this volume. This is not possible at this time because comparable data is not currently available for a laser survivability enhanced SAB Bus.

2.2.3 IMPACT OF ISOTOPE FUEL COST

The NIMS Bus unit cost presented in Table 2.2-2 do not include costs for the Pu-238 isotope fuel required by the DIPS in the NIMS Electrical Power System (EPS). These costs are nominally quoted by the DOE in terms of dollars-per-watt (thermal) encapsulated. Encapsulated refers to the fuel containment system required or space use of nuclear power to ensure safety throughout all normal operation and accident environments. Each baseline NIMS, as defined in this study, required 7200 Watts(t) of Pu-238.

Figure 2.2-1 presents the NIMS Bus unit cost as a function of the Pu-238 isotope fuel costs. These costs are based on 1973 prices quoted to DOD by the then AEC*, and include an annual seven (7) percent inflation to bring them up to 1979 levels. It is seen that advanced fuel production techniques could result in cost increments of \$700,000-to-\$800,000.

*Letter to Dr. M. R. Currie, Director, DR&E, DOD from
Chairman, Military Liaison Committee to the USAEC, June 1974.

BASELINE NIMS (DIPS)
 REQUIRES 7200 WATTS (t)
 OF PU-238 FUEL

FUEL COSTS SHOWN ARE
 CORRECTED FROM 1973
 AEC ESTIMATES TO 1979
 DOLLARS USING SEVEN (7)
 PERCENT ANNUAL
 INFLATION (FACTOR OF
 ~1.5)

Figure 2.2-1. Impact of
 PU-238 Fuel Cost on NIMS
 Bus Unit Cost for Flight
 Systems

about six (6) percent of the total unfueled NIMS Bus cost. This fuel cost increment increases to \$2,000,000 to \$3,000,000 for large quantity (300 kg) procurement of the fuel using current fuel production techniques, about 20 percent of the total unfueled NIMS Bus cost. A 300 kg quantity of Pu-238 will provide fuel for more than 20 DIPS units, each producing 1200 Watts(e) at the end of a 10-year mission, the NIMS design point.

In the worst case, the isotope fuel cost would be \$6,000,000 to \$7,000,000 based on current fuel production techniques, about 50 percent of the unfueled NIMS Bus cost. This would occur if only one or two NIMS flight units were built. These costs are comparable to the fuel costs charged to users such as NASA for Radioisotope Thermoelectric Generator (RTG) units used for spacecraft EPS for outer planet exploration missions.

The actual fuel costs in all cases are subject to negotiations between the user agency and the DOE.

2.2.4 NIMS COST/BENEFITS ASSESSMENT

This paragraph delineates the estimated cost increments attributed to the NIMS Bus which provides its enhanced laser threat survivability at the SMATH IV level, relative to the SAB Bus.

The incremental NIMS Bus development cost is \$14.54 million, per the data of Table 2.2-1. The incremental NIMS Bus unit cost is \$1.53 million, plus the isotope fuel cost, per the data of Table 2.2-2. The isotope fuel costs are taken to be those representative of large quantity production by conventional techniques. This is valid for comparison with SAB Bus costs for missions in which many (5-25) spacecraft are required. A fuel cost of \$487.50 per Watt(thermal), encapsulated is assumed in 1979 dollars. This corresponds to the midpoint of the costs of \$300 per Watt(t)-to-\$350 per Watt(t) quoted to the DOD by the AEC in 1973 dollars*. The baseline NIMS requires 7200 Watts(t) of Pu-238,

*op. ct.

which therefore translates into a cost of \$3.51 million for each NIMS Bus. The total NIMS Bus unit cost to provide enhanced laser survivability is then estimated at \$5.04 million in 1979 dollars, including the \$3.51 million fuel cost. This assumes that the NIMS development costs are written off and not amortized over any NIMS production run.

The impact of amortizing the NIMS and SAB development costs over a number of units is presented on Figure 2.2-2. The NIMS fuel costs are included at a constant value of \$3.51 million per unit. The costs estimated to provide enhanced laser survivability using the NIMS concept decrease from \$8 million for the fifth flight unit, down to \$5.7 million for the twentieth unit.

Costs necessary to provide the same level of enhanced laser survivability for a SAB Bus are unknown at this time because comparable data is not available.

2.3 MULTIMISSION APPLICATIONS

Complete compatibility with the NIMS Bus was established for all of the six DOD missions evaluated. These six missions are:

- 1) Defense Meteorological Satellite Program (DMSP), the next (BLOCK 6) generation.
- 2) The next generation of the Defense Satellite Communications Systems (DSCS) denoted here are DSCS IV.
- 3) The Nuclear Forces Communications Satellite (NFCS), previously denoted as SSS.
- 4) The General Purpose Synchronous Communications Satellite (GPSCS).
- 5) The Global Positioning Satellite (GPS) - Phase III.
- 6) The Deep Space Surveillance System (DSSS).

Figure 2.2-2. Enhanced Laser Survivability is Cheap with Nuclear Power

The DMSP payload integration is presented on Figure 2.3-1. The other five mission payload configurations are presented on Figure 2.3-2. All but DSSS will mount vertically into the STS. DSSS is an IUS-launched vehicle and as such is mounted horizontally within the cargo bay. All of the payloads are contained within the NIMS diameter of 12 feet. Preliminary fields-of-view analyses show that all requirements are met for these missions.

For all of these missions except the DMSP and the DSSS, a 62-inch SRM is used to place the spacecraft into the transfer orbit and a bi-propellant system used for circularization and plane change, where required.

2.3.1 DMSP-NIMS ORBITAL CONFIGURATION

A representative payload complement was selected for the DMSP based on instruments currently used. The Microwave Imager is the one exception. The version shown here has a four foot parabolic antenna - about twice that being considered for DMSP Block 5D-2. The OLS is redundant to insure long life capability for that mission need.

A bi-propellant system is used to place the DMSP vehicle into its final orbit of 450 NM from the Shuttle altitude of 150 NM. The large solid rocket motor (SRM) is not required for this application. The TDRSS link antenna is stowed in the SRM well during launch and is erected after the final orbit is achieved.

2.3.2 NFCS - NIMS ORBITAL CONFIGURATION

The Nuclear Forces Communications Satellite (NFCS) (formerly called SSS) is to provide emergency message relay capability to and from the tactical nuclear forces. There will be four spacecraft in a 110,000 NM polar orbit. The high orbit aids in making the system survivable. In addition, each vehicle carries enough fuel for a 2000 foot per second maneuvering capability. Orbit transfer and circularization is accomplished through the use of the 62-inch SRM and the bi-propellant system. Alternatively,

Figure 2.3-1. DMSP-NIMS Orbital Configuration

Figure 2.3-2. Multimission Applicability Established

the SRM can be removed and two spacecraft can be launched simultaneously by the IUS into the transfer orbit with final orbit insertion done by the bi-propellant system.

2.3.3 DSCS IV - NIMS ORBITAL CONFIGURATION

The antenna payload complement shown here is identical to that of DSCS III. The differences between the DSCS III and DSCS IV missions has been assumed to be a 50 percent increase in the number of transponder channels for the DSCS IV mission. DSCS III has four 10 Watt SHF channels and two 40 Watt SHF channels. For DSCS IV, these have been increased to six 10 Watt and three 40 Watt SHF channels.

2.3.4 GPSCS - NIMS ORBITAL CONFIGURATION

The General Purpose Synchronous Communications Satellite (GPSCS) mission combines elements from DSCS III (19 beam and 61 beam - Multi-Beam Antennas), UHG System (SCT - emergency communications), and upper K-band receive and transmit subsystems. It is the next generation experimental military communications satellite.

2.3.5 GPS ØIII - NIMS ORBITAL CONFIGURATION

The GPS ØIII payload complement consists of a navigation subsystem with an SHF secure uplink and L-band downlink, the SCT subsystem for emergency communications to tactical forces, and the IONDS subsystem which provides nuclear blast detection information.

In comparison with the other mission payloads, this one is relatively small and low in weight. There are ample margins in both weight and volume to accommodate other secondary payloads on this vehicle (e.g., civil navigation).

2.3.6 DSSS-NIMS ORBITAL CONFIGURATION

The Deep Space Surveillance System (DSSS) mission configuration shown here is the largest of the configurations considered. The on-orbit

weight is close to 5000 pounds and uses the IUS to place it into its final orbit. To provide the high pointing accuracy and the slewing rates assumed a six control moment gyro (CMG) system is used.

At the time this study was started, there was no good definition on the DSSS sensor, so the SIRE sensor was used as being typical as far as size, weight and power requirements.

It was assumed that the refrigeration unit of the active solar cooler could be modified to eliminate the 2400 Watt electrical power requirement. The approach would be to use another isotope heat source to provide the thermal energy directly instead of converting the electrical energy into thermal energy as it is now done on the SIRE sensor*.

2.3.7 NIMS ALTERNATE MISSIONS WEIGHT SUMMARY

Table 2.3-1 summarizes the various mission spacecraft weights starting at the bottom with the system weight as installed in the STS. From that point upwards, the weights are shown at each step following launch through on-orbit.

The spacecrafts on-orbits weights are shown down to the level necessary to indicate the subsystem elements which vary as a function of mission.

2.4 REDUCED MISSION CONSTRAINTS

The use of DIPS can potentially remove many of the constraints normally imposed on solar array-powered spacecraft. Many of these constraints are due to the elimination of the large solar arrays required while other constraints are relaxed or removed because vehicle orientation for power collection or thermal protection is not required.

* Nuclear Heat Sources for Cryogenic Refrigerators in Space, B. Raab, A. Schock, W.G. King, IECEC 759134, 1975.

TABLE 2.3-1 NIMS ALTERNATE MISSIONS WEIGHT SUMMARY

ITEM	WEIGHT IN POUNDS					
	GPS	DSCS IV	GPSCS	DMSP	SSS	DSSS
NIMS S/S	1,448	1,448	1,448	1,448	1,448	1,448
DRY BI-PROP	644	644	644	365	511	191
PAYLOAD	400	700	700	1,034	640	1,438
CONTINGENCY	408	291	291	353	222	423
(%)	(16.4)	(10.4)	(10.4)	(12.4)	(8.5)	(13.8)
ORBIT FUEL	100	747	747	200	758	900
S/C ORBITAL WT.	3,000	3,830	3,830	3,400	3,579	4,400
ΔV BI-PROP FUEL	3,532	3,141	3,141	1,322	1,989	$\left(\begin{array}{c} \text{IUS:} \\ 32,500 \\ 200 \end{array} \right)$
PKM	8,345	1,200	11,200		12,660	
LAUNCH ADAPTER	100	100	100		100	
EJECTED WEIGHT	14,977	18,271	18,271	4,722	18,328	37,100
CRADLE	2,800	2,800	2,800	2,900	2,900	8,000
LAUNCH CONTINGENCY	500	500	500	500	500	500
STS P/L WEIGHT	18,277	21,571	21,571	8,122	21,728	45,600

2.4.1 RELAXATION OF MISSION CONSTRAINTS

The use of the DIPS system for both power and active thermal control for a spacecraft minimizes or eliminates mission constraints in all phases of a space mission ranging from launch through on-orbit operations as summarized on Table 2.4-1. For example, launch window availability is constrained by the need to collect power during the launch phase of a conventional solar powered spacecraft and by the thermal constraints normally imposed by passive and/or semi-active thermal systems. With the DIPS, the power collection constraint is eliminated and the thermal constraints greatly reduced, if not completely eliminated.

2.4.2 MISSION PERFORMANCE IMPROVEMENTS

On-orbit mission and spacecraft performance are significantly improved through the elimination of large solar arrays. This eliminates potential solar array-payload interferences, flexible body/ACS interactions, and the need for unique orientations to accommodate power collection requirements while satisfying payload orientation requirements. Additionally, more nearly-spherical spacecraft designs are possible resulting in increased orbital accuracy predictions over longer periods of time. This feature is attractive for missions requiring high accuracy of orbit predictability such as GPS and DMSP.

2.5 NIMS/DIPS SCHEDULES COMPATIBLE

The possible DIPS program is shown on Figure 2.5-1, and is superimposed on the schedule for the two missions targeted for an early 1980's start; DMSP - Block 6 and NFCS (SSS). The projected availability of the DIPS qualification and flight units is seen to be compatible with the development and launch dates for these two missions. Utilization of the DIPS in the NIMS Bus or similar concept is similarly compatible with these mission schedule requirements. The other four missions assessed would

Figure 2.4-1. NIMS Reduces Mission Constraints Relative to Solar Array/Battery Systems

Figure 2.5-1. Possible Dynamic Isotope Power System Program Compatible with Mid-80's DOD Missions

occur in the mid-to-late 1980s and are therefore also compatible with the NIMS/DIPS projected development.

It is noted that the DIPS program is currently not funded beyond FY-1980 by the Department of Energy. Continued development will require funding support from the user agency.

SECTION 3

GUIDELINES

This section presents the key guidelines employed in the definition of the NIMS Bus. These are listed on Table 3-1.

The definition of a nuclear-powered spacecraft bus was required to permit the attributes assessment of the DIPS. This bus must be fully capable of meeting all requirements of the six missions considered. Accomplishment of this design in the most cost-effective way requires maximum standardization of the multi-mission bus and all of its support subsystems. These include the Tracking, Telemetry and Communications (TT&C) subsystem, the Attitude Control System (ACS), the Thermal Control System (TCS), and the propulsion system; the perigee and apogee functions. The Electrical Power System is also standardized in that the DIPS is used together with standard harness and electronic payload switchgear.

The bus is to enhance survivability against specified nuclear and laser environments. To this end, the bus and payload thermal control system is integrated with the DIPS radiator to maximize survivability against the laser threat. The approach to enhance survivability from the nuclear threat maximizes use of design techniques and procedures being employed on other spacecraft programs being conducted from DOD.

The requirement that the spacecraft has to be of a modular design was established to simplify fabrication and test. This approach permits the NIMS Bus development with only limited dependence on the mission payloads, and the parallel assembly and test of the NIMS Bus and the payloads.

Since the missions considered are all in the mid-80's to mid-90's time frame, the requirement of STS compatibility is a must. The on-board

TABLE 3-1 GUIDELINES FOR NIMS BUS DEFINITION

- DEFINE SPACECRAFT WITH MULTI-MISSION PAYLOAD CAPABILITY
- STANDARDIZE:
 - CONFIGURATION
 - TRACKING, TELEMETRY AND COMMUNICATIONS (TT&C)
 - ATTITUDE CONTROL SYSTEM (ACS)
 - THERMAL CONTROL SYSTEM (TCS)
 - PROPULSION
 - PERIGEE AND APOGEE FUNCTIONS
- PROVIDE FOR PAYLOAD THERMAL CONTROL SYSTEM INTEGRATED WITH DIPS RADIATOR
- DESIGN FOR SURVIVABILITY TO NATURAL AND HOSTILE MAN-MADE SPACE ENVIRONMENTS
- PROVIDE FOR SEPARATE FABRICATION, ASSEMBLY AND TEST OF BOTH NIMS AND THE MISSION PAYLOADS
- ASSURE COMPATIBILITY WITH STS LAUNCH
- ON-BOARD PROPULSION SELECTION MUST CONSIDER BOTH
 - INITIAL DEPLOYMENT MODE
 - REPLACEMENT MODE

propulsion system is required to place the spacecraft into its final orbit starting from the low earth orbit of the STS (nominally 160 NM circular). The selection of this on-board propulsion system must consider both the initial deployment and the replacement modes. For example, although multiple spacecraft launch with the IUS on-board propulsion system may be cost effective for mission initial deployment, an alternate propulsion system may be more attractive when the eventual satellite replacement requirement is also considered.

The DIPS design requirements and specifications are utilized in the NIMS definition. Key items are:

1) Lifetime	10 years
2) Power level (EOM)	1200 watts
3) Weight	450 lbs.
4) Reliability (10 year)	0.93

These are further detailed in Appendix A, Volume II of this report.

SECTION 4

NUCLEAR INTEGRATED MULTI-MISSION SPACECRAFT (NIMS) DESCRIPTION

This section presents a summary description of the NIMS Bus. The detailed design trades and system description are presented in Volume II of this report.

4.1 SPACECRAFT SYSTEMS APPROACH TO SPACE NUCLEAR POWER

The systems approach employed in the NIMS Bus consists of three basic elements, as illustrated on Figure 4.1-1. This concept provides the ability to manage thermal energy and combines this with the capability for separate payload and NIMS development, fabrication and test.

4.1.1 PUMPED COOLANT LOOP UTILIZATION

The DIPS Rankine Cycle pumped coolant is used for electronics and other subsystem cooling for both normal operations and during threat encounter. This is accomplished by oversizing the radiator, above that required to reject waste heat from the DIPS, to provide for electronics cooling. Specifically, the NIMS radiator is sized to reject about 6900 Watts(t); 1000 Watts(t) from the NIMS housekeeping and/or mission dependent payload electronics and 5900 Watts(t) from the DIPS. The DIPS working fluid is cooled to 80°F (27°C), 45°F below the 135°F (57.6°C) minimum nominally required by the DIPS Rankine Cycle, in order to provide an 80°F heat sink for electronics cooling. In addition, the coolant tubes in the NIMS tube-and-fin radiator are spiraled circumferentially around the NIMS cylindrical surface. Each of the four (4) tubes makes 1.25 complete

Figure 4.1-1. Spacecraft Systems Approach to Space Nuclear Power

circuits while transversing the 6.3 feet from the hot-to-cold end of the cylinder. Thus, some of the thermal energy absorbed from the threat on the illuminated side of the NIMS is transported to the non-illuminated side of the NIMS, and re-radiated to space. Coatings on the radiator surface limit the energy absorbed to 5 percent or less of that incident.

4.1.2 PAYLOAD/ELECTRONICS INTEGRATION

The payload and NIMS housekeeping electronics are mounted on an annular panel located inside the NIMS radiator envelope. As shown schematically, low temperature heat pipes are employed to collect the waste heat from the electronics and dump this thermal load into the DIPS working fluid at the cold (80°F) NIMS radiator exit header. The panel(s) (cold plate) are bolted or otherwise mechanically attached to the radiator exit header.

4.1.3 MULTIMISSION CAPABILITY

The payload(s) can be developed, fabricated and tested with a large degree of independence from the same sequence for the NIMS Bus, guided by suitable interface specifications. Shortly before launch, the payload is integrated with the NIMS Bus. Flow charts substantiating this approach have been developed and are included in the Summary Volume.

4.2 NIMS CONFIGURATION SELECTION

The NIMS Configuration requirements were established based on the mission payloads and bus support subsystem definitions and/or requirements. The key NIMS requirements illustrated on Figure 4.2-1, are:

1. Provide 237.5 Ft² integrated radiator area.
2. House 62 inch diameter solid rocket perigee kick motor (PKM).
3. Provide 66 Ft² (minimum) upper bulkhead component mounting area (heat pipe coupled to radiators).

Figure 4.2-1. NIMS General Arrangement

- 4) Provide 35 inch minimum internal clearance.
- 5) Provide maximum vertical payload clearance when installed in STS.

The baseline configuration concept was selected on the basis of providing the required mounting area with adequate growth margin, minimizing the Shuttle cargo bay volume required, and providing a modular interface between the bus and the mission payloads. The salient features of the selected configuration are:

- 1) 144" (12 Ft.) Diameter radiator - 76 inches high.
- 2) Central 64" diameter cylinder with 8 radial keels - contains PKM and provides primary launch load path.
- 3) Modular upper bulkhead provides 80 Ft² for component mounting (20 percent margin for growth).
- 4) 20 Ft² (2 bays) used for housekeeping components--60 Ft² (6 bays) reserved for payload components.
- 5) STS vertical clearance 65.3 inches from radiator rim (80 inches from recessed upper bulkhead).
- 6) Highest volumetric efficiency and simplest radiator and heat pipe designs.

The NIMS configuration is dominated by the 238 sq. ft. heat rejection radiator, 12 feet in diameter by 6.3 feet high. Approximately 50 percent of this thermally and mechanically integrated structure is required to reject the 5900 Watts thermal waste heat from the DIPS. The remainder provides a lower, 80°F temperature heat sink for up to 1000 Watts thermal of housekeeping and payload electronics cooling.

4.3 NIMS DESIGN FEATURES

The design features of the NIMS, shown on Figure 4.3-1, fully satisfy all of the requirements placed on the vehicle. Payload accommodations are provided on the large earth-viewing face with no fields-of-view obstructions from any of the bus subsystems. The TT&C subsystem, based on the DSCS III design, is fully compatible with the Air Force's SGLs system and incorporates both security and A/J protection. The Propulsion Subsystem uses a large solid rocket motor to provide the energy necessary to place the spacecraft into a transfer orbit with perigee at the STS altitude and apogee at the desired altitude (i.e., 10,900 NM for GPS; 19,323 NM for DSSS, DSCS IV, GPSC; 110,375 NM for SSS). Orbit circularization and plane change is accomplished by a bi-propellant system. The bi-propellant system can also be used to provide on-orbit agility for those missions which are compatible with this mode of survivability enhancement. The structure is designed to handle the worst case weights/loads. It provides for modularity and is closed off to provide a "Faraday Cage" to minimize EMP effects. The DIPS provides 1200 Watts(e) power full-time over the 10-year design life of the NIMS. The DIPS can be conveniently adapted to meet any mission power requirement from 500 Watts(e) to over 2500 Watts(e).

The attitude control subsystem is a 3-axis bias momentum type. It uses the DIPS momentum as the stabilizing element. No spacecraft spin-up is required for orbit injection. The bi-propellant system provides for 3-axis stabilization during PKM/AKM burn.

Thermal control of the bus and payload components is provided by the DIPS active cooling loop through radial heat pipes from the spacecraft's equipment mounting surface.

All electronic equipment used are either from DSCS III or derived from that program.

Figure 4.3-1. NIMS Features

Figure 4.2-1 presented the top side views of the NIMS Bus. In the top view the preliminary locations for the bi-propellant system fuel and pressurant tanks and the DIPS power system components are shown. The DIPS generator is mounted along the NIMS pitch axis which, due to its 17.6 foot-pound-seconds of uncompensated momentum, provides the pitch bias momentum.

The side view is shown within the STS cargo bay envelope to show the available volume for the payload sensors/antennas. Also shown are typical electronic equipment envelopes. The 62-inch perigee kick motor (PKM) is shown mounted into the NIMS. The control thrusters are located on the vehicle's on-orbit center-of-gravity (CG) to minimize torques when the thrusters are used.

The exploded view of the NIMS Bus presented on Figure 4.3-2 shows the basic system modularity concept. At the forward end (shown in the lower left-hand corner) are the Equipment Mounting Panels. This can be built up and tested independent of the rest of the bus. The integrated radiator slides over and is attached to the core structural module. This radiator is not used as a load carrying member. The core structure, after fabrication, has the bi-propellant fuel and pressurant tanks and the DIPS generator and the heat source assemblies (less the isotope heat sources) mounted in it. The center cylinder is the main load carrying member. The loads from the Equipment Panels are carried into this cylinder through the core structure bulkheads. The NIMS is attached to the STS launch cradle by means of an attach fitting between the cradle and the center cylinder. Provisions are made for installing the isotope heat sources into the heat source assemblies at the launch site prior to NIMS installation in the STS.

4.4 NIMS-STS VERTICAL INSTALLATION

The preliminary concept to mount the NIMS in the STS vertically is shown in Figure 4.4-1. The cradle used for the NIMS is basically the Standard Test Rack (STR) previously developed by GE as a multi-purpose cradle for

Figure 4.3-2. NIMS Exploded View

Figure 4.4-1. NIMS-STS Vertical Installation

shuttle use. The NIMS takes up about one-quarter of the cargo bay (~15 feet).

NIMS would not be the first nuclear powered spacecraft to be launched by the STS. Both the Galileo (1982 launch) and Solar Polar (1983 launch) NASA missions are scheduled for STS launch. These spacecraft are powered by Radioisotope Thermoelectric Generators (RTG's).

4.5 WEIGHT AND PERFORMANCE SUMMARY (SYNCHRONOUS MISSIONS)

4.5.1 PERFORMANCE

The NIMS provides continuous full time power over its ten year design life from the integrated Dynamic Isotope Power System. The power level varies from a maximum of 1300 Watts(e) at Beginning of Mission (BOM) to 1200 Watts(e) minimum at the end of ten years. This change is entirely due to the radioactive decay of the Plutonium-238 isotope fuel. No other degradation modes are identified.

The pointing accuracy provided by the 3-axis attitude control system is 0.08° in pitch and roll, and 1.0° in yaw. This performance is required by the synchronous missions evaluated. Higher pointing accuracies up to 0.01° in pitch roll and yaw are available to meet requirements imposed by the GPS and DMSP missions. The NIMS reliability is estimated at 0.68 for its 10 year design life, including a 0.93 ten year reliability for the DIPS. The integrated thermal control system provides for temperature control within $\pm 1^\circ\text{C}$.

4.5.2 WEIGHT BREAKDOWN

The major weight elements of the dry NIMS Bus presented on Table 4.5-1 are the structure, the DIPS and the propulsion system. The DIPS weight reflects only that portion of the radiator weight required for power generation. The weight of the portion of the same integral radiator

TABLE 4.5-1 NIMS WEIGHT SUMMARY - SYNCHRONOUS MISSIONS

<u>ITEM</u>	<u>WEIGHT, POUNDS</u>
STRUCTURE	375.
SPACECRAFT RADIATOR	83.
DIPS	450.
THERMAL CONTROL	105.
TT&C	121.
POWER DISTRIBUTION/CONTROL	183.
ATTITUDE CONTROL	105.
PROPULSION (DRY)	689.
BALLAST/ESD	<u>25.</u>
SPACECRAFT TOTAL (DRY)	2137.
ORBIT FUEL	747.
AVAILABLE FOR P/L & CONTINGENCY	<u>946.</u>
TOTAL S/C WEIGHT	3830.

utilized for electronics and other subsystem cooling is included in the thermal control weight budget.

About 950 pounds are available for the payload (and contingencies) to be integrated with the NIMS Bus. Orbit fuel requires about 750 pounds, for a total spacecraft (NIMS plus payload) weight in orbit of just over 3800 pounds.

This weight breakdown is for synchronous missions. Differences exist for higher orbit missions such as S³, and for lower orbit missions such as GPS and DMSP. However, all six mission payloads evaluated are accommodated by the NIMS Bus.

4.6 NIMS ASSEMBLE, TEST AND LAUNCH FLOW

The modular NIMS spacecraft has been designed to permit parallel and independent assembly and test of the payload, DIPS and spacecraft subsystems as illustrated on Figure 4.6-1.

The spacecraft contractor is responsible for final spacecraft assembly and fabricates structural subassemblies or fixtures using close tolerance master tooling to control all assembly interfaces. The payload sensor support structure and payload equipment panels (with heat pipes attached) are shipped to the Payload Contractor for installation and compatibility testing of the payload, and a MAGE fixture is sent to the DIPS contractor for assembly and test of the DIPS including the external radiator. The Spacecraft Contractor (or propulsion sub-contractor) installs and leak tests the all welded Propulsion Subsystem on the core structure, and the Spacecraft Contractor assembles and tests the house-keeping subsystem panels. All of these Payload, DIPS and Spacecraft Subsystem assembly and test activities are conducted in parallel minimizing the time and cost effects caused by interdependent series assembly and tests at the subassembly level.

At the completion of all subsystem, DIPS and payload testing, the units

are shipped to the Spacecraft Contractor for spacecraft final assembly. The DIPS is first mated to the core structure/propulsion assembly followed by installation of the interconnecting electrical harness and internal insulation. The payload and housekeeping equipment panels are attached to and connected next and the payload and housekeeping sensors are mounted and aligned. Installation of the external insulation blankets and (if required), the inert PKM completed the spacecraft assembly. Note that the PKM, the Launch ASE and the Isotope Heat Sources are also fabricated and tested in parallel with the spacecraft fabrication and assembly cycle.

At the conclusion of spacecraft final assembly, system level vibration, thermal vacuum and acoustic acceptance tests are conducted and at their conclusion, the spacecraft, PKM, IHS and ASE are all shipped to the launch site for assembly and check-out prior to installation and launch by the STS.

Figure 4.6-1. NIMS Parallel Assembly and Test Flow