DOE/NE/32129--T4

Rockwell International Rockwell International Division		ENGINEERING PRODUCT DOCUMENT																									
GO NO. 95890	S/A NO. 45101	PAGE 1 OF 28	TOTAL PAGES 29	REV LTR/CHG NO. SEE SUMMARY OF CHG Rev. B	NUMBER EID-00093																						
PROGRAM TITLE Dynamic Isotope Power System (DIPS)																											
DOCUMENT TITLE NASA Low Power DIPS Conceptual Design Requirements Document																											
DOCUMENT TYPE Engineering Information Document			RELATED DOCUMENTS None																								
ORIGINAL ISSUE DATE		REL. DATE 10-9-90		APPROVALS R. B. Harty	DATE 9-4-90																						
PREPARED BY/DATE G. Johnson		DEPT 635	MAIL ADDR HB21	APPROVALS A. G. Stadnik																							
W. Determan		635	HB21	9-4-90																							
W. Otting		635	HB21																								
IR&D PROGRAM? YES ☐ NO ☒ IF YES, ENTER AUTHORIZATION NO.																											
DISTRIBUTION			ABSTRACT																								
<table border="1"> <thead> <tr> <th>* NAME</th> <th>MAIL ADDR</th> </tr> </thead> <tbody> <tr> <td>Baumeister, E.</td> <td>HB15</td> </tr> <tr> <td>* Metcalf, K.</td> <td>HB05</td> </tr> <tr> <td>* Cubillos, F.</td> <td>HB25</td> </tr> <tr> <td>* Determan, W.</td> <td>HB21</td> </tr> <tr> <td>* Dix, T.</td> <td>HB21</td> </tr> <tr> <td>* Felten, L.</td> <td>HB23</td> </tr> <tr> <td>* Harty, R.</td> <td>HB21</td> </tr> <tr> <td>Johnson, R. A.</td> <td>HB13</td> </tr> <tr> <td>* Otting, W.</td> <td>HB21</td> </tr> <tr> <td>* Rutherford, P.</td> <td>HB07</td> </tr> </tbody> </table>			* NAME	MAIL ADDR	Baumeister, E.	HB15	* Metcalf, K.	HB05	* Cubillos, F.	HB25	* Determan, W.	HB21	* Dix, T.	HB21	* Felten, L.	HB23	* Harty, R.	HB21	Johnson, R. A.	HB13	* Otting, W.	HB21	* Rutherford, P.	HB07	<p>This document describes the requirements for a low power (0.5-1.0 kwe) DIPS for interplanetary and space exploration missions using the Mariner Mark II spacecraft. The reference mission used to establish these requirements was the Cassini orbiter mission to Saturn. Requirements specific to two other missions (Outer Planet Orbiter/Probe and Comet Nucleus Sample Return) are also included. A list of references used to develop these requirements is provided.</p> <p style="text-align: center; font-size: 2em; font-weight: bold;">MASTER</p> <p style="text-align: center;">DISTRIBUTION OF THIS DOCUMENT IS LIMITED TO DOE OFFICES AND DOE CONTRACTORS</p> <p style="text-align: center;">jpe</p>		
* NAME	MAIL ADDR																										
Baumeister, E.	HB15																										
* Metcalf, K.	HB05																										
* Cubillos, F.	HB25																										
* Determan, W.	HB21																										
* Dix, T.	HB21																										
* Felten, L.	HB23																										
* Harty, R.	HB21																										
Johnson, R. A.	HB13																										
* Otting, W.	HB21																										
* Rutherford, P.	HB07																										
* COMPLETE DOCUMENT NO ASTERISK, TITLE PAGE/SUMMARY OF CHANGE PAGE ONLY			RESERVED FOR PROPRIETARY/LEGAL NOTICES THIS REPORT MAY NOT BE PUBLISHED WITHOUT THE APPROVAL OF THE DOE OFFICE OF PATENT COUNSEL DISCLAIMER This report was prepared as an account of work sponsored by an agency of the U.S. Government. Neither the U.S. Government nor any agency thereof, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the U.S. Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the U.S. Government or any agency thereof. VI.D-2																								

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

REV	SUMMARY OF CHANGE	APPROVALS AND DATE
A	<p>Updated Mission Requirements Matix (Table 1) to include battery, EMI, and safety requirements.</p> <p>Updated subsection 2.3.6 to reflect new EMI reference.</p> <p>Revised subsection 2.3.8 to incorporate safety criteria and references.</p> <p>Incorporated Figure 2 "MMII Low Power DIPS Envelope."</p> <p>Added references 15-17 to document.</p> <p>Updated Appendix B, Section B.2.4 to incorporate new particle fluence values in Table T205-3-240:3-36.</p>	<p><i>William R. Detman</i> 9/17/90</p> <p><i>ROB Katz</i> 9-17-90</p> <p><i>[Signature]</i> 9-17-90</p> <p>Release Date: 9-19-90</p>
B	<p>Updated Mission Requirements Matrix (Table 1) to change battery size from 165 W-Hr to 5 A-Hr.</p> <p>Added footnotes to Table 1 (page 5).</p> <p>Updated Section 2.3.8, Safety Criteria, to include CNSR Earth return nuclear safety requirement.</p>	<p><i>William R. Detman</i> 10/5/90</p> <p><i>ROB Katz</i> 10-8-90</p> <p><i>J.C. Mills for</i> <i>R.A. Johnson</i> 10-8-90</p> <p>Release Date: 10/9/90 JC</p>

TABLE OF CONTENTS

	<u>Page</u>
1.0 Introduction	3
2.0 Low Power DIPS Requirements	4
2.1 General	4
2.2 Mission Requirements	4
2.3 Mission Requirements Comparison	4
2.3.1 Launch Date	4
2.3.2 Power Level	4
2.3.3 Source Impedance	12
2.3.4 Mass	12
2.3.5 Volume and Area	12
2.3.6 EMI Requirements	12
2.3.7 Torque, Vibration, and Angular Momentum	12
2.3.8 Time With No Heat Source Cooling	12
2.3.9 Mission Environments	12
3.0 Design Issues and Additional Considerations	16
4.0 References	17

Appendices

A. MMII Spacecraft Typical Power Profile	19
B. Environmental Design Requirements	22
B.1 Space Vacuum	22
B.2 Solid Particles	22
B.2.1 Cometary Dust	22
B.2.2 Meteoroids	23
B.2.3 Space Debris	25
B.2.4 Saturn Ring Particles	26
B.2.5 Asteroids	28
B.2.6 Titan Atmosphere	28

List of Tables

Table 1	NASA Low Power DIPS Study - Mission Requirements Matrix	5
Table 2	CNSR Spacecraft Power Budget	11

List of Figures

Figure 1	MMII Cassini Cruise Configuration - BOM	13
Figure 2	MMII Low Power DIPS Envelope	14
Figure A-1	Typical Power Required Immediately After Launch	20
Figure A-2	Typical Power Required During Mission Operations	21

1.0 INTRODUCTION

NASA has funded the DOE for FY90 to perform a conceptual design study of a low power Dynamic Isotope Power System (DIPS). The objective of this study is to develop a conceptual design of a low power DIPS (LPD) system at 500 to 1000 We which can be used as the power source for a Mariner Mark II spacecraft for upcoming space exploration and science missions.

This document describes the power system requirements for a low power DIPS for these unmanned interplanetary space exploration missions using the Mariner Mark II spacecraft. The reference mission used to establish these requirements is the Cassini orbiter mission to Saturn. Requirements specific to two other missions (Outer Planets Orbiter Probe (OPD/P) and Comet Nucleus Sample Return (CNSR)) are also included in the summary tables.

During the low power DIPS conceptual design study, a reference DIPS conceptual design will be developed based on the Cassini mission requirements, and the options to this reference design will be developed for the other two missions. There are other NASA space exploration and science missions such as the Mars rover/sample return, where a DIPS may be a viable alternative to Radioisotope Thermoelectric Generators (RTGs). However, to maximize the design and integration evaluation effort, the mission set was limited to three similar mission types. A list of references used to develop this set of requirements is provided along with additional references on radioisotope thermoelectric generator (RTG) specifications and environmental and test specifications for the GPHS-RTG on the Galileo/Ulysses missions. Since the LPD could replace the RTG, these existing references would likely form the basis for a LPD specification.

2.0 LOW POWER DIPS

2.1 GENERAL: The Mariner Mark II (MMII) spacecraft power system design currently incorporates two 250 We RTGs as a power source for the mission set being considered. The electrical bus architecture of the MMII design requires adapting the Low Power DIPS design to meet the requirements as developed for an RTG power source, but also evaluating what MMII-RTG specific features may be combined with the LPD features to provide an optimum power system.

There are two fundamental system design requirements for the MMII spacecraft electrical power subsystem. These are:

1. **Uninterruptible Electrical Power Supply:** The power source unit shall provide an uninterrupted power supply to the MMII main spacecraft electrical bus immediately prior to launch and continuing through end-of-mission.
2. **Single Point Failure:** Redundancy techniques shall be used to the maximum extent practical to prevent the catastrophic loss of electrical power due to single point failures. Residual single failures shall be subject to failure modes and effects analysis. The analysis must demonstrate that for every potential mode of a single point failure, adequate inspection/tests are performed to maximize mission success.

2.2 MISSION REQUIREMENTS: The specific design requirements for the conceptual design are contained in the Mission Requirements Matrix in Table 1. The requirement parameter (e.g., mass) is delineated in Column 1 of Table 1. Mission requirements for the Cassini reference case, Outer Planets Orbiter/Probe and the Comet Nucleus Sample Return missions, are given in Columns 2-4, respectively. A reference from Paragraph 4 for each mission requirement is shown next to the specific requirement by the number in parenthesis. This provides traceability to research the requirements further, if needed.

2.3 MISSION REQUIREMENTS COMPARISON: Most of the requirements to be used in developing the LPD conceptual design are similar for all three mission cases. The following differences and clarifications are highlighted in terms of developing the conceptual design. The Table 1 requirement shall be the governing design requirement unless superseded in the following subparagraphs.

2.3.1 Launch Date: The Cassini mission launch is scheduled for 1996. The associated development schedule for a LPD to support this launch date should be based on flight system delivery by mid-1995. The OPO/P mission launch date has not been established. For program plan purposes, the CNSR launch date in December 2000 will be used.

2.3.2 Power Level: The DIPS shall be sized to meet all power demands. A battery system shall be provided to (1) maintain full power and support two (2) switchovers to the stand-by DIPS power conversion loop and (2) provide sufficient power to the spacecraft bus from the time of launch to the time the

TABLE 1

NASA Low Power DIPS Study – Mission Requirements Matrix

Mission	Reference Case: MM II	Outer Planets Orbiter/Probe	Comet Nucleus Sample Return
Mission duration (yr)	10.3 (1)	12.0 (7)	8.0 (2)
Power system lifetime (yr)	12.0 (1)	12.0 (1)	12.0 (1)
Launch date	1/1/00*** (8)	NA*	12/20/00 etc. (2)
Nominal power level (We)	500 (1)	500 (1)	500 (2)
Average power (We)	410 (1)	410 (1)	420 (2)
Peak power (We) (EOM)	484 (1)	480 (1)	481 (2)
Peak power duration	10 days (Appendix A)	10 days (Appendix A)	25 days (2)
Power profile available/attached	Yes (Appendix A)	Yes (Appendix A)	Yes (Table 2)
Battery size (A-hr)	5.0**	5.0**	5.0**

* N/A - Not available

** Based upon maximum current discharge rate limits for NiCd batteries

*** The reference mission uses a 2000 A.D. launch date but all other requirements are from the Cassini mission to Saturn, which will use RTG power sources

Note: Numbers in parenthesis indicate Section 4.0 reference number

TABLE 1 (CONTD)

NASA Low Power DIPS Study – Mission Requirements Matrix

Mission	Reference Case: MM II	Outer Planets Orbiter/Probe	Comet Nucleus Sample Return
User bus voltage	30 Vdc (1)	30 Vdc (1)	30 Vdc (1)
Voltage regulation (% of bus value) ss**	±2.5 (1)	±2.5 (1)	±2.5 (1)
(% of bus value) <2 ms	±5.0 (1)	±5.0 (1)	±5.0 (1)
Voltage ripple, mv (p-p)	170 (goal) (9)	170 (goal) (9)	170 (goal) (9)
(100 Hz – 20 MHz)	450 (max) (6)	450 (max) (6)	450 (max) (6)
Source Impedance	≤0.1 Ω (0-10 kHz) (1)	≤0.1 Ω (0-10 kHz) (1)	≤0.1 Ω (0-10 kHz) (1)
Mass, kg (goal)	141.3 kg*	141.3 kg*	141.3 kg*
Volume, m₃	See Figure 2	See Figure 2	See Figure 2
Area, m₂	See Figure 2	See Figure 2	See Figure 2

* DIPS replaces all items in power & pyrotechnics subsystem except pyro subsystem & power distribution unit.
Ref. Mass Status Summary for CRAF as of 4/18/90 provided by M. Shirbacheh, JPL.

** Steady State

Rockwell International
Rockwell International
Rockwell International Division

90c-29-20-2B
M900

EID-00093
Page 6

TABLE 1 (CONTD)

NASA Low Power DIPS Study – Mission Requirements Matrix

Mission		Reference Case: MM II	Outer Planets Orbiter/Probe	Comet Nucleus Sample Return
Radiation limits at S/C electrical bus	Neutron Gamma	8×10^9 n/cm ² (13) 800 rads	8×10^9 n/cm ² (13) 800 rads	8×10^9 n/cm ² (13) 800 rads
Thermal limits		1.4 kw/m ² (6)	1.4 kw/m ² (6)	1.4 kw/m ² (6)
EMI requirements		GLL-Spec. 625-261 (15)	GLL-Spec. 625-261 (15)	GLL-Spec. 625-261 (15)
Max change in angular (N-m-sec) momentum	x-axis, z-axis y-axis	≤ 1.0 (14) ≤ 0.5	≤ 1.0 (14) ≤ 0.5	≤ 1.0 (14) ≤ 0.5
Max torque limits (N-m)	x-axis, z-axis y-axis	0.12 (14) 0.06	0.12 (14) 0.06	0.12 (14) 0.06

Rockwell International
Rocketdyne Division

90c-29-20-3B
M900

EID-00093
Page 7

TABLE 1 (CONTD)

NASA Low Power DIPS Study – Mission Requirements Matrix

Mission	Reference Case: MM II	Outer Planets Orbiter/Probe	Comet Nucleus Sample Return
Torque disturbance limits (N-m) (due to TAC speed change)	0.005 (14)	0.005 (14)	0.005 (14)
Vibration limits max force on S/C due to TAC static imbalance (N)	0.216 (14)	0.216 (14)	0.216
Max torque on S/C due to TAC dynamic imbalance (N-m)	0.0548 (14)	0.0548 (14)	0.0548 (14)
Reliability (best estimate, goal) and meet single point failure design criteria	95% (12)	95% (12)	95% (12)

TABLE 1 (CONTD)

NASA Low Power DIPS Study – Mission Requirements Matrix

Mission	Reference Case: MM II	Outer Planets Orbiter/Probe	Comet Nucleus Sample Return
Launch vehicle	Titan IV/Centaur (1)	Titan IV/Centaur (1)	Titan IV/Centaur (1)
Launch vehicle requirements (shock & vib. thermal, envelope, etc.)	Titan IV users handbook (8)	Titan IV users handbook (8)	Titan IV users handbook (8)
Safety criteria	GLL FSAR & ref. 17 (16 & 17)	GLL FSAR & ref. 17 (16 & 17)	GLL FSAR & ref. 17 (16 & 17)
Mission environmental criteria	Appendix B	Appendix B	Appendix B

TABLE 1 (CONTD)

NASA Low Power DIPS Study – Mission Requirements Matrix

Mission	Reference Case: MM II	Outer Planets Orbiter/Probe	Comet Nucleus Sample Return
Sink temperature variations			
BOM EOM	206–262K (13) 89K (11)	206–262K (13) 50K (11)	206–262K (13) 100K (11)
Meteroroids environments	Appendix B	Appendix B	Appendix B
Protection criteria	0.99 probability without penetration of fluid containment boundary (12)	0.99 probability without penetration of fluid containment boundary (12)	0.99 probability without penetration of fluid containment boundary (12)
Debris	Appendix B	Appendix B	Appendix B
Structural			
Stiffness (natural frequency)			
Stowed	11 Hz (1)	11 Hz (1)	11 Hz (1)
Deployed	0.5 Hz (1)	0.5 Hz (1)	0.5 Hz (1)

CNSR

SPACECRAFT POWER BUDGET

ACC. TO MATRA TELECOPY CNSR/CE/153.89 AND DORNIER ESTIMATE

MISSION PHASES	CRUISE BOM	COMET APPR.	COMET LAND.	CORE SAMPL.	SURF. SAMPL.	SAMPLE LOAD	CRUISE BEFORE RTG EJECT	CRUISE AFTER RTG EJECT
TIME DURATION DAYS SINCE LAUNCH	0 TO 1653	1653 TO 1703	1703 TO 1728	1728 TO 1753	1728 TO 1753	1728 TO 1753	1753 TO 2870	2870 TO 2873
CRUISER POWER	246.1	280.9	276.7	276.7	276.7	266.7	276.7	266.7
LANDER POWER	20	90	76	141	64	64	-	-
ERC POWER	-	-	-	-	-	-	-	20
SUBTOTAL	266.1	370.9	351.7	417.7	330.7	309.7	276.7	286.7
MARGIN (ABOUT 15 %)	39.9	56.1	53.3	63.3	47.3	47.3	42.3	43.3
BATTERY CHARGING	40	40	40	-	20	20	40	-
TOTAL SYSTEM POWER REQUIREMT.	346	467	445	481	401	377	359	330

ALL POWER VALUES IN WATT

DIPS unit is started up and achieves full power. The Centaur battery may be used to provide spacecraft power until DIPS startup. The secondary battery must be rechargeable from the DIPS and have 25% margin associated with performance criteria (1) above. Appendix A provides the typical power profiles to be met during launch, startup, and mission cruising. The CNSR mission may require a higher electrical power level (up to 720 watts electric) if the radioisotope heater units (RHUs) on the spacecraft are replaced with electrical heater units due to mission safety criteria.

2.3.3 Source Impedance: The power system source impedance shall be as prescribed by Table 1 and an estimate of the impedance up to 20 Mhz shall also be provided.

2.3.4 Mass: The 141.3 kg goal shall also consider mass savings in the MMII spacecraft associated with integrating the LPD with the existing spacecraft design. Such savings may include decrease of spacecraft armor and structure due to integration of the DIPS radiator and combination of power system control functions with the MMII control computer. The total DIPS package mass shall be identified along with a listing of mass savings due to integration with the MMII spacecraft.

2.3.5 Volume and Area: Based on the May 1990 MMII spacecraft configuration shown in Figure 1, the LPD envelope shall be as shown in Figure 2. Radiator/radiation area requirements shall be based on staying within the envelope whether the radiator is fixed or deployed. Deployed radiators shall also consider the added structural mass for deployment and subsequent Centaur or MMII engine burns. For the CNSR mission, the envelope shall consider whether manipulator/robotic arms may intrude the reference envelope.

2.3.6 EMI Requirements: References 11 and 15 EMI requirements include magnetic field limitations such that at rated power the magnetic field shall be less than 30 nano-tesla at 1 meter from the center of the TAC and less than 1 nano-tesla at 2 meters from the center of the TAC.

2.3.7 Torque, Vibration, and Angular Momentum: The change in angular momentum and uncanceled torques imparted to the spacecraft due to power conversion subsystem (PCS) startup/switch-over operations should be minimized, thus minimizing the load and torques introduced into the spacecraft and the response required from the MMII's attitude and articulation control subsystem (AACS). To achieve this, the TAC rotor's axis should be oriented with respect to the spacecraft axis such that the moments/torques created act on the spacecraft axis with the largest moment of inertia; typically the X or Y axis. See Figure 1 for axis orientations.

2.3.8 Safety Criteria: Safety criteria for the Low Power DIPS shall be based upon the same design approach and reentry analyses techniques employed in the Galileo FSAR document (Ref. 16). Accident evaluations shall be based upon the use of a Titan IV/Centaur launch vehicle. In addition to these requirements, the DIPS fuel clad temperature limits defined in Reference 17 shall be used in all LPD safety analyses. The CNSR mission scenario requires return of the spacecraft to an Earth capture orbit. Within three to seven days of Earth

Figure 1 MMII Cassini Cruise Configuration - BOM

Figure 2 MMII Low Power DIPS Envelope

return, the radioisotope power source for the spacecraft will be ejected and the spacecraft will then be maneuvered into an Earth capture orbit. An on-board small photovoltaic array will be used to supply minimal spacecraft power needs during the final return days. Ejection of the radioisotope power source will ensure a 1,000 kilometer orbital altitude for this source for its closest approach to Earth. The safety requirements for the CNSR mission shall be the same as developed for the Gallileo mission as defined in the GLL FSAR (Ref. 16).

2.3.9 Mission Environments: The mission environments for all three missions are significantly different and may result in design differences between the reference mission case and the OPO/P and CNSR missions. The additional armor/redundancy impacts in terms of added weight shall be identified. Also, any differences due to EOM sink temperature differences shall be highlighted. The end of mission sink temperature for the CNSR mission is actually the sink temperature during comet rendezvous since the spacecraft will return a sample to Earth. The gas and dust models during Comet rendezvous is based upon the CRAF mission environment, as defined in Appendix B. Appendix B identifies which environment requirements apply to each of the missions.

3.0 DESIGN ISSUES AND ADDITIONAL CONSIDERATIONS

The list of references provided in Section 4.0 gives detailed background as well as traceability to the Table 1 requirements. Two RTG specification documents (References 12 and 13) for the Galileo/Ulysses missions provide the most relevant performance requirements information for the Low Power DIPS/MMII conceptual design.

4.0 REFERENCES

1. "Cassini Mission: Saturn Orbiter Proposal Information Package," JPL PD 699-11, Vol. IV, Oct. 10, 1989.
2. Noordwijk, Estec; "Rosetta System Definition Study, Phase 2 Presentation," Matra Espace, Jan. 23, 1990.
3. Cockfield, R. D., et. al.; "RTG Power Sources for the International Solar Polar Mission," General Electric Co., 15th IECEC, pp. 1043 - 1046, 1980.
4. "CRAF/Cassini Project: Power & Pyrotechnics Subsystem (PPS)," JPL 699-205-4-2004, March 29, 1990.
5. Brandewie, R., et. al.; "Lockheed Missiles and Space Company BSTS Power System Definition Study," Rockwell International, Rocketdyne Division, RI/RD86-188, 1986.
6. "Design Requirements Specification For The Dynamic Isotope Power Subsystem (DIPS) Engineering Unit (EU), Rev. A," Rockwell International, Rocketdyne Division, CP409R0007, April 21, 1989.
7. Determan, W.; "Power System Requirements For The Mariner Mark II Spacecraft," Phone Conversation and transmittals from Mike Shirbacheh (JPL), June, 1990.
8. "Titan IV Radioisotope Thermoelectric Generator Safety Data Book, Volume V, Integrated Mission Summary," Contract # F04701-85-C-0019, Martin Marietta, MCR-88-2559, March 1989.
9. "Magellan Project," JPL IS-3271152.
10. "Preconceptual Design of Low Power 0.5-1.0 kWe DIPS Systems for Interplanetary Missions, Presentation to DoE," Contract # DE-AC03-88NE32129, Rockwell International, Rocketdyne Division; BD 89-111, Nov. 1989.
11. J. Haffner, et. al.; "Environments of the Outer Solar System," North American Rockwell, Space Division, Pub. 2547-M, June, 1971.
12. "Joint International Solar Polar Mission and Galileo Orbiter Radioisotope Thermoelectric Generator (RTG) Requirements Specification," JPL Spec: ES 512397, March 31, 1981.
13. "Environmental Criteria and Test Requirements for the GPHS-RTG, Revision T," General Electric, NS0020-05-04, May 9, 1985.

References Continued

14. "Calculations on Mariner Mark II Spacecraft Angular Momentum Torques and Vibration Limits for DIPS," Roel Van Bezooijen, JPL, July 25, 1990.
15. GLL Specification 625-261, Rev. C, "Electromagnetic Compatibility Control Requirements" Document, R. Kuberry, Jet Propulsion Laboratory, July 1, 1988.
16. "Final Safety Analysis Report for the Galileo Mission, Volume II (Book 2), Accident Model Document - Appendices," 87SDS4213, GE Astro-Space Division, Spacecraft Operations, Contract DE-AC01-79ET32043, December 15, 1988.
17. "DIPS Fuel Clad Temperature Limits," ER-00027, Rockwell International, Rocketdyne Division, Contract DE-AC03-88NE32129, April 28, 1989.

APPENDIX A

MMII SPACECRAFT TYPICAL POWER PROFILE

Figures A-1 and A-2 show the typical required power for the LPD study mission set immediately after launch and during subsequent cruise and fly-by events. The LPD shall be capable of meeting the required power levels shown here for the Galileo mission. Elapsed time of zero hours shall correspond to the Titan/Centaur launch for assessment purposes.

GALILEO Spacecraft Transient Power at Separation from Shuttle

Figure A-1 Typical Power Required Immediately After Launch

LRP November 29, 1989

EID-00093
Page 20

GALILEO Spacecraft RTG Power Status Report

Launch October 18, 1989

Figure A-2 Typical Power Required During Mission Operations

LRP November 22, 1989

EID-00093
Page 21

APPENDIX B

ENVIRONMENTAL DESIGN REQUIREMENTS

The environmental design requirements shall apply to all three missions identified in paragraph 2.2 of EID-00093 unless otherwise indicated herein. These requirements are taken from JPL Document 205-3-240, dated May 30, 1990, Environmental Design Requirements (for CRAF/Cassini), pp. 66-76. The OPO/P environmental requirements and the reference Cassini environmental requirements shall be considered identical at this time. Unit designations such as m[2] and cm[3] mean square meters and cubic centimeters, respectively.

B.1 SPACE VACUUM: All flight equipment shall be designed to withstand pressures which decrease from $1.0E5 \text{ N/m}^2$ (760 Torr) to $1.3E(-12) \text{ N/m}^2$ ($1.0E(-14)$ Torr) in space.

B.2 SOLID PARTICLES

B.2.1 COMETARY DUST: All flight equipment shall be designed to function within specification when exposed to the following cometary dust criteria:

B.2.1.A. (CNSR only) Cometary dust grains having radii ranging from 0.1 micro m to a few cm are present, in decreasing concentrations, in the comet, dust tail, and interplanetary space. They contain mineral units having sizes near one or a few micro m (e.g., enstatite, forsterite, or FeS) and near a few tenths of micro m (e.g., other iron and magnesium silicates). Although these individual units have densities near 3 to 5 g/cm[3], the larger grains are irregular, porous aggregates of such units, possibly mixed or coated with organic mantles, and have smaller densities, typically near 1 g/cm[3], and a large range of optical and material properties (e.g., albedo, strength, etc.). Interplanetary dust particles collected in the Earth's stratosphere are probably the best available analogs. The above description of the cometary dust properties is based on the best current knowledge. Some fraction (perhaps less than 0.5) of the grains may be considered as dirty water ice rather than dust at the same density, 1g/cm[3].

Results from two alternative models for Comet Kopff appear in the upper and lower halves of JPL Table F205-3-240:E, "Comet Kopff Gas and Dust Models for CRAF," representing dust production in the general background and in a dust jet, respectively. The background dust model (upper half of the table, and as scaled for time and position) applies throughout the post-rendezvous portions of the mission, whereas the other model (lower half of the table also as scaled for time and position) applies when the Spacecraft is in an active dust jet (0.05 of the time). In this table, the dust flux entries in Columns 3 through 7 represent the results of integration over the interval between the dust thresholds in Columns 1 and 2 (mass in kg, radius in m) and the thresholds in the following row, their units are $\text{m}^{-2}\text{s}^{-1}$ (interval number flux, Column 3), s^{-1} (area, Col. 4), $\text{kg/m}^2\text{s}$ (mass, Col. 5), N/m^2 (pressure, Col. 6), and W/m^2 (heating - Col. 7). This table should be

obtained from JPL.

For the CNSR mission, dependencies on target comet identity, and on time, of the comet activity and Spacecraft position and velocity all lead to distinct variations in the dust flux. For many purposes it is reasonably accurate to model these dependencies using the simple scaling considerations provided in Section 4 of F205-3-240:E, "Comet Kopff Gas and Dust Models for CRAF, Appendix E," to be obtained from JPL (Bill Nesmith) on September 10, 1990.

For design purposes the interval dust fluence (i.e., the integral of flux over time) is useful for predicting the expected value (AF) of the number of impacts within some time interval on an exposed area A normal to the relative velocity vector. Poisson statistics suggest that the corresponding probability of no impact is e^{-AF} for dust particles in this mass interval. Similar considerations can be applied to the trajectory legs of the various mission phases, and to several Spacecraft component areas, in order to assess the dust collection capability, impact damage risk, and other consequences of the dust environment for the CNSR mission. Such consequences should be considered in at least three general areas:

- a) production of surface contamination and injection of vapor and plasma into the near-Spacecraft environment,
- b) impact damage, ranging from surface erosion through spallation, penetration, disruption, and
- c) perturbations of Spacecraft attitude and trajectory.

Effects (a) through (c) are arranged in order of increasing particle size, i.e., decreasing flux and fluence; for the largest sizes a probabilistic analysis (with appropriate risk considerations) could be required. Note that for some of the above consequences there may be strong dependencies on dust particle composition, structure, and relative velocity.

The uncertainty in these results is large, perhaps an order of magnitude or more. A more thorough assessment of this uncertainty, and continued improvement of the dust models, is anticipated in the future. For CNSR, a scoping assessment of the impact of comet dust/particles should be performed using the models in F205-3-240:E, referenced above.

B.2.2 METEORIODS (All 3 LPD Missions) All flight assemblies shall be designed to function within specification during and after exposure to the meteoroid fluence (nominal levels, no margin) tabulated in T205-3-240:3-22, "Fluence Distributions for Interplanetary Meteoroids." While exposed to this environment the Spacecraft shall be designed to execute its mission with a 95% probability of success using a Poisson distribution.

T205-3-240:3-22 Fluence Distributions for Interplanetary Meteoroids 10/09/89

Mass-M (g)	Cometary Fluence (Particles/m ² Mass Greater or Equal to M)	Asteroidal Fluence (Particles/ m ² Mass Greater or Equal to M)	Probability of no Impacts on One Sq Meter S/C Area	
			Cometary	Asteroidal
1E-6	1.8 (1)	1.9 (0)	1.5230E-8	0.149569
1E-5	1.1 (0)	2.8 (-1)	0.332871	0.755784
1E-4	7.1 (-2)	4.1 (-2)	0.931462	0.959829
1E-3	4.3 (-3)	6.0 (-3)	0.995709	0.994018
1E-2	2.6 (-4)	8.6 (-4)	0.999740	0.999140
1E-1	1.6 (-5)	1.2 (-4)	0.999984	0.999880
1	1.0 (-6)	1.8 (-5)	0.999999	0.999982
10	6.1 (-8)	2.6 (-6)	1.0	0.999997
100	3.7 (-9)	3.7 (-7)	1.0	1.0

Mean Asteroidal Velocity (km/s) = 13.1

Mean Cometary Velocity (km/s) = 16.9

Mean Meteoroid Density	Cometary	(g/cm**3)	= 0.5
	Asteroidal	(g/cm**3)	= 2.8

B.2.3 SPACE DEBRIS: (All 3 LPD Missions) During those portions of each mission conducted near the Earth, the Spacecraft will be exposed to the bombardment by space debris. The space debris flux is directional and varies with altitude and duration. All assemblies shall be designed to function within specification during and after exposure to the space debris fluence in T205-3-240:3-23, "Earth Space Debris Fluence," with mission probability of success of 95 percent using a Poisson distribution.

T205-3-240:3-23 Earth Space Debris Fluence 09/27/89		
PARTICLE DIAMETER (cm)	PARTICLE MASS (g)	TOTAL FLUENCE (m-2)
-----	-----	-----
1.00E-6	1.47E-18	2.36E+1
1.00E-5	1.47E-15	9.05E+0
1.00E-4	1.47E-12	2.55E+0
1.00E-3	1.47E-9	1.30E-1
1.00E-2	1.47E-6	1.24E-5
1.00E-1	1.47E-3	7.82E-8
1.00E+0	1.47E+0	1.76E-10
1.00E+1	2.67E+2	2.28E-11
1.00E+2	4.85E+4	1.09E-11
1.00E+3	8.83E+6	1.09E-12
-----	-----	-----

B.2.4 SATURN RING PARTICLES: (Reference and OPO/P) This environment shall be considered the reference environment for the LPD and the impact of any variation for particles covered by other mission environmental design criteria shall be assessed. T205-3-240:3-24, "Saturn Ring Particle Fluence for Two Orbits" presents integral fluence information for Saturn ring particles based on small, intermediate and large particle models, for two initial, 23 degree, inclined orbits. The relative impact velocity is 17.1 km/s and the average particle density is 0.5 gm/cm³ for these orbits. This environment is highly dependent upon mission trajectory. The values shown are based on the current mission plan for Saturn.

T205-3-240:3-24 Saturn Ring Particle Fluence for Initial Two Orbits

Fluence (m-2)			
PARTICLE MASS (g)	SMALL PARTICLE MODEL	INTER- MEDIATE MODEL	LARGE PARTICLE MODEL
1.0(-9)	15	2.4(2)	1.1(4)
1.0(-8)	0.72	36	2.6(3)
1.0(-7)	3.3(-2)	5.1	6.3(2)
1.0(-6)	1.5(-3)	0.74	1.5(2)
1.0(-5)	6.9(-5)	0.11	36
1.0(-4)	3.3(-6)	1.6(-2)	5.5
1.0(-3)	1.5(-7)	2.2(-3)	0.55
1.0(-2)	6.9(-9)	3.3(-4)	0.055
0.1	3.3(-10)	4.7(-5)	5.5(-3)
1	1.5(-11)	6.8(-6)	5.5(-4)

Note: The fluence is estimated at a ring plane crossing distance of 2.7 Saturn radius, for two initial, 23 degree inclined orbits.

The LPD shall be designed to withstand the Saturn ring particle fluence for all subsequent orbits defined in T205-3-240:3-36, "Saturn Ring Particle Fluence for All Mission Orbits" and function within specification. The fluence is based on small, intermediate and large particle models for all orbits having inclinations between 0 and 60 degrees and ring plane crossings between 2.4 and 6.0 Rs. The average impact velocity is between 7.5 and 15 km/s. For design purposes 15 km/s should be used.

T205-3-240:3-36 Saturn Ring Particle Fluence for All Mission Orbits				11/01/89
Fluence(m-2)				
PARTICLE MASS (g)	SMALL PARTICLE MODEL	INTER- MEDIATE MODEL	LARGE PARTICLE MODEL	
1.0(-9)	9.21(+3)	9.21(+3)	1.78(+5)	
1.0(-8)	4.27(+2)	4.27	3.84(+4)	
1.0(-7)	19.8	9.8	7.17(+3)	
1.0(-6)	0.921	1.73	9.63(+2)	
1.0(-5)	4.27(-2)	0.254	1.49(+2)	
1.0(-4)	1.98(-3)	3.73(-2)	20.6	
1.0(-3)	9.21(-5)	5.48(-3)	2.46	
1.0(-2)	4.27(-6)	8.04(-4)	0.305	
0.10	1.98(-7)	1.18(-4)	4.62(-2)	
1.0	9.21(-9)	1.73(-5)	8.00(-3)	
Note: The fluence is estimated for ring plane crossings between 2.4 and 6.0 Rs for all orbits having inclinations between 0 and 60 degrees.				

B.2.5 ASTEROIDS: (Reference and OPO/P Missions) The Cassini baseline mission design includes flyby of the asteroid Maja at approximately 3320 km. The asteroid environment, at the present time, is not known well enough to provide environmental models. This is a placeholder for the asteroid environment design requirements until more information becomes available, (e.g., from the Galileo flyby of the two asteroids). For design purposes, this shall be considered an open design issue to be assessed for the effected missions to determine LPD armor mass impacts.

B.2.6. TITAN ATMOSPHERE: (Reference Mission) While flybys of Saturn's largest satellite Titan are planned. The environmental effects data shall not be considered in the LPD design at this time, but shall be identified as an open design issue to be assessed for both the reference mission and the OPO/P mission.