87

N91-19200

Dual-Purpose Self-Deliverable Lunar Surface PV Electrical Power System

Jack H. Arnold, David W. Harris and Eldon R. Cross
Rockwell International, Rocketdyne Division
Canoga Park, CA

Dennis Flood
NASA Lewis Research Center
Cleveland, OH

Introduction

A safe haven and work support PV power system on the lunar surface will likely be required by NASA in support of the manned outpost scheduled for the post-2000 lunar/Mars exploration and colonization initiative. For purposes of this paper, a lunar surface outpost power was baselined for a daylight power level of 50-kW, and 25-kW during the night, although no critical limitations were discovered to prevent the implementation of higher power levels.

The concept presented in this paper provides the means of delivering a moderately large power system to the moon by employing the PV array to power an electrical propulsion module to take the system from LEO to the Moon. The vehicle is then placed in lunar orbit and descends to the lunar surface using conventional chemical rockets.

In order to support a 50-kW load on the lunar surface, a raw EOL array power of about 100-kW is required. As can be seen in the ensuing LTV (Lunar Transit Vehicle) power degradation modeling, the LTV BOL array size must be increased because of the transit time the system spends as it exits the Earth's atmosphere, and the attendant Van Allen radiation. This period is somewhat variable, but will be in the neighborhood of 140-days, or the approximate equivalent of a radiation fluence of 1×10^{15} electrons per cm^2 if 20-mil thick solar cell coverglass shielding is employed.

After landing on the lunar surface, the electrical power system will reconfigure itself so that during daylight hours the array bus will not only support the safe haven load, but will also operate a water electrolyzer. The resulting hydrogen and oxygen will be stored in insulated storage tanks. During the lunar night, these gases will operate fuel cell modules to support the loads, the resulting water returned to the water storage system for recirculation.

For the system modeled in the paper, a high-pressure electrolyzer was employed based on technology the Navy is developing for undersea applications. Water stored under ambient pressure is delivered to the electrolyzer using a high-pressure pump at about 3000 psi. From the electrolyzer, the resulting gases are stored in insulated flasks. During the lunar night, the gases are regulated down to between 60 and 100 psi and delivered to a fuel cell stack sized to the required night bus loads, remembering that by nature fuel cells are capable of handling highly variable transient loads.

Single-Axis Solar Array Tracking

The study revealed that the solar array should be provided with a single axis of tracking for maximizing the solar electric conversion process both during the in-transit phase, and during lunar surface operation; this shows that one-axis tracking reduces the array size by 50%, and substantially lowers the mass and volume of other system components, including electrolyzer and fuel cell.

Initial On-Orbit Configuration and Mass Analysis

The following section includes an initial configuration of the LTV as it launches from Space Station Freedom and begins its journey to the Moon, including the electric propulsion module which can be subsequently jettisoned when lunar orbit is achieved.

It should be noted that the electric propulsion "truck"can be designed to be reusable and recoverable, a substantial incentive when the concept is compared with conventional delivery systems.

This section also provides the configuration and preliminary analysis of the lunar surface power system when it switches over to the electrolyzer and fuel cell mode, remembering that during the in-transit flight the array will directly feed the electric propulsion bus, and will convert to the surface mode after landing.

Up and down link telecommunications for performance monitoring and control, plus fault detection and correction are in the preliminary planning stages.

Orbital Trajectory Preliminary Analysis

This section presents the initial orbit and trajectory analyses and the initial assumptions used for the preliminary computer codes. Naturally, it was necessary to assume certain system characteristics associated with the power system, various masses, and the array power (see Table 1). As new iterations and second generation design models are generated, they will be fed back into the codes for reiterative system upgrading. Figure 2 shows the results of the orbital trajectory analysis.

Earth Magnetosphere Radiation Analysis and Preliminary LTV Power System Model (Including Initial Assumptions)

This section presents the initial radiation and array degradation analysis based on the first iteration orbit and trajectory models developed. Clearly, this must be continually upgraded as the system model changes.

Figure 3 is a plot of the Yearly Radiation Fluence versus Altitude for varying orbital inclinations. From this figure it can be seen that as the inclination increases the total yearly fluence decreases. Also, 7000 nmi is the altitude with the highest level of radiation flux. The flight path inclination for this analysis was assumed to be at the Space Station Freedom inclination of about 30°. Figure 4 shows the effect coverglass thickness has on the yearly fluence at this inclination. To relate the flight time to the radiation data in the JPL Radiation Handbook the flight time was broken into discreet time periods relating to the altitude found in the handbook. Figure 5 is a plot of the time spent at each altitude. Due to the lack of data for the region from GEO to a lunar orbit, the flight time remaining after the LTV has reached 18000 nmi was lumped together and assumed to be at GEO altitude, hence the jump in the curve near 19000 nmi. The total fluence for the complete flight to the moon as a function of coverglass thickness is shown in Figure 6. Figure 7 shows the accumulative fluence seen by a cell as the LTV position increases in altitude along the flight path. It can be seen that by time the LTV has reached 9000 nmi it has received most, if not all of the total fluence. Figures 9, 10 and 11 show the effect of the fluence on maximum power for Si, GaAs/Ge and InP cells respectively. How radiation degradation effects the array mass is shown in figure 11. This mass is for an array that is capable of delivering the assumed 247 kW at a post-lunar transfer/pre-lunar descent condition. Once on the lunar surface the array power will degrade due to the increase in cell operating temperature. Finally, Figure 12 shows the cost of launching different propulsion types of LTV's to LEO. It can be seen that at today's STS costs and at Shuttle-C launch costs the use of a Solar Electric-Ion can provide a significant cost savings.

Also, it should be remembered that the initial analysis was based on remaining on the Space Station Freedom inclination after leaving Freedom and exiting the magnetosphere, which does not appear to be the most benign course through the Van Allen belts. If more benign inclinations are discovered during subsequent analysis, plane change scenarios will be evaluated and new array degradation and shielding requirements will be integrated into the modeling process.

Conclusions and General Observations

1. Initial system modeling and computer analysis shows that the concept is workable and contains no major high risk technology issues which cannot be resolved in the circa 2000-2025 timeframe.

A specific selection of the best suited type of electric thruster has not been done; the initial modeling was done using an ion thruster, but Rocketdyne must also evaluate arc and resisto jets before a final design can formulated.

2. As a general observation, it appears that such a system can deliver itself to the Moon using many system elements that must be transported as dead payload mass in more conventional delivery modes.

3. It further appears that a larger power system providing a much higher safe haven power level is feasible if this delivery system is implemented, perhaps even sufficient to permit resource prospecting and/or lab experimentation.

4. The concept permits growth and can be expanded to include cargo transport such as habitat and working modules. In short, the combined payload could be manned soon after landing and checkout.

5. NASA has expended substantial resources in the development of electric propulsion concepts and hardware that can be applied to a lunar transport system such as described herein. In short, the paper may represent a viable mission on which previous investments play an invaluable role.

6. A more comprehensive technical paper which embodies second generation analysis and system size will be prepared for near-term presentation.

TABLE 1. GROUND RULES AND ASSUMPTIONS

- SOLAR POWER SYSTEM SIZED FOR 50/25 KW DAY/NIGHT
- POWER AVAILABLE FOR PROPULSION = 247 KW
- SOLAR POWER SYSTEM WEIGHT = 16894 LB
- LUNAR ORBIT INSERTION AND LANDING PERFORMED WITH CHEMICAL PROPULSION
- LO2 AND LH2 TANKS ARE INITIALLY FILLED AND USED FOR PROPULSION (CAPACITY = 7333 LB)
- TOTAL O2/H2 REQUIRED IS 13130 LB
- WEIGHT LANDED ON MOON = 17704 LB (INCLUDING 810 LB OF PROPULSION SYSTEM INERTS)
- WEIGHT IN LUNAR ORBIT AFTER SEPARATION FROM TRANSFER STAGE = 30834 LB
- BURN TIMES INCREASED APPROXIMATELY 5% TO ACCOUNT FOR TIME SPENT IN EARTH'S SHADOW
- TANKAGE FOR ELECTRIC PROPULSION = .144 X PROPELLANT WEIGHT

TABLE 2. PROPULSION SYSTEM CHARACTERISTICS

	ION ENGINE	ARCJET	CHEMICAL
THRUST LEVEL, LB	2.227	4.026	15K
SPECIFIC IMPULSE, SEC	3000	1000	482.8
ENGINE WEIGHT, LB	4169	2062	342
DELTA V, FT/SEC	21400	21400	12150
WEIGHT IN LEO, LB	45311	74057	77647
PROPELLANT WEIGHT, LB	9010	35977	42130
TANK AND STAGE WEIGHT, LB	1297	5181	4681
BURN TIME, DAYS,(MINUTES)	137	103	(23)
APPROX. TRIP TIME, DAYS	144	109	3-5

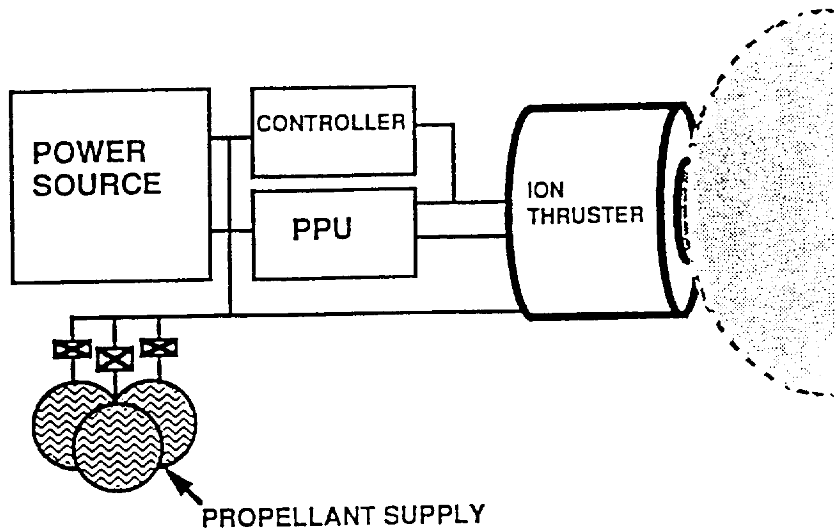

Figure 1: Ion Propulsion System Block Diagram

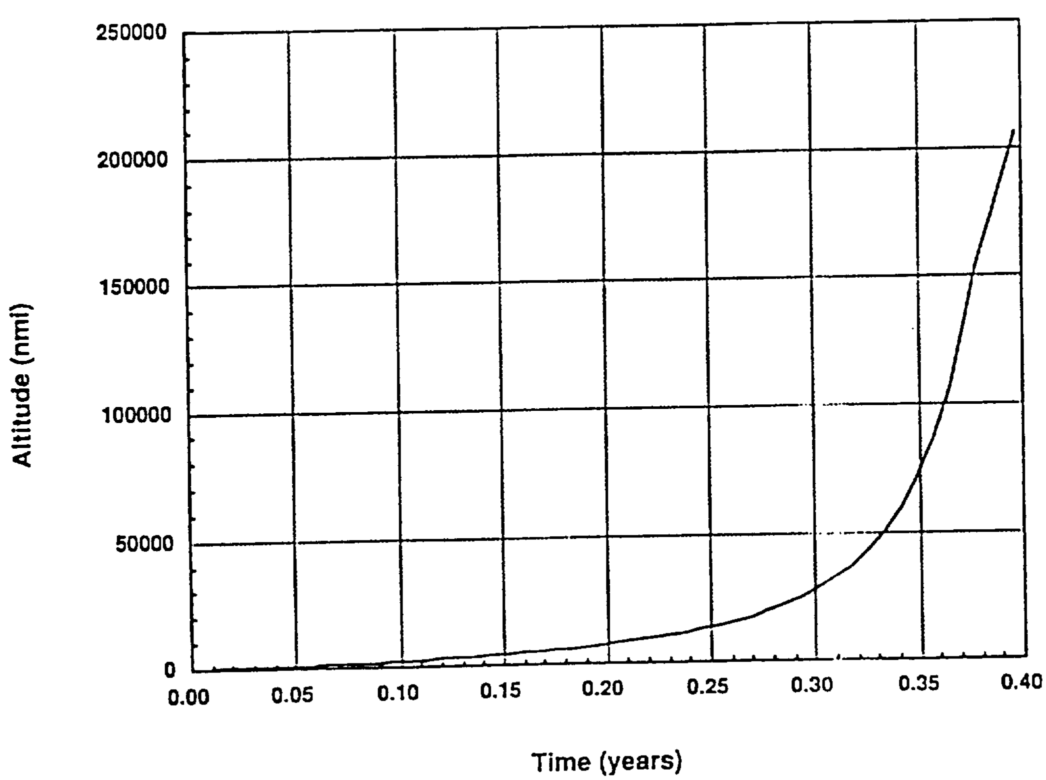

Figure 2: Photovoltaic LTV Flight Profile

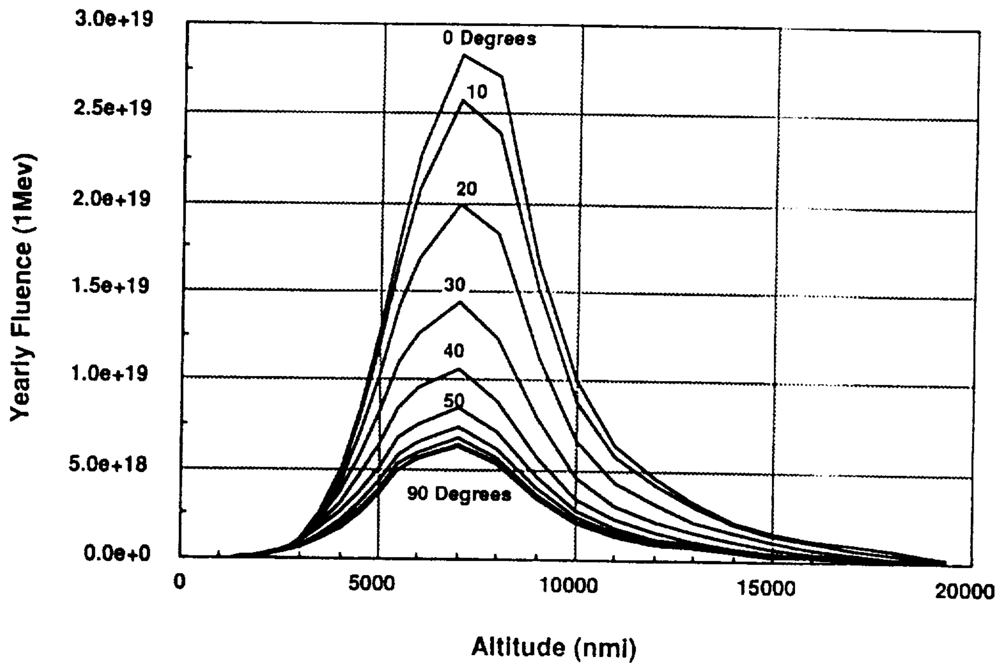

Figure 3: Yearly Fluence vs Altitude for Various Inclinations

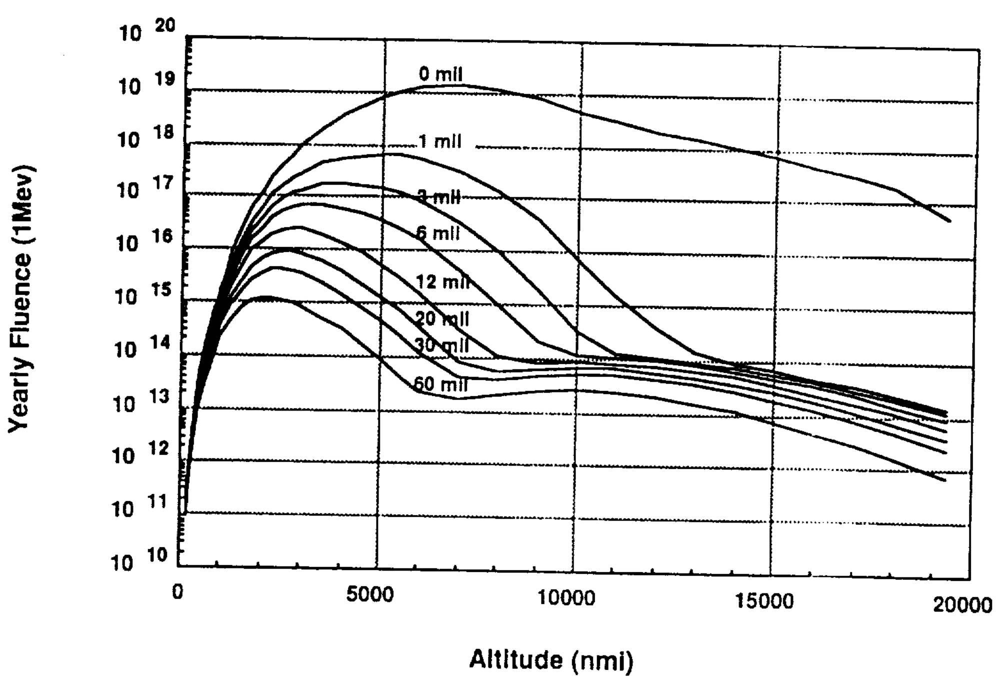

Figure 4: Yearly Fluence vs Altitude for Various Cover Glass Thickness at 30 Degrees Inclination

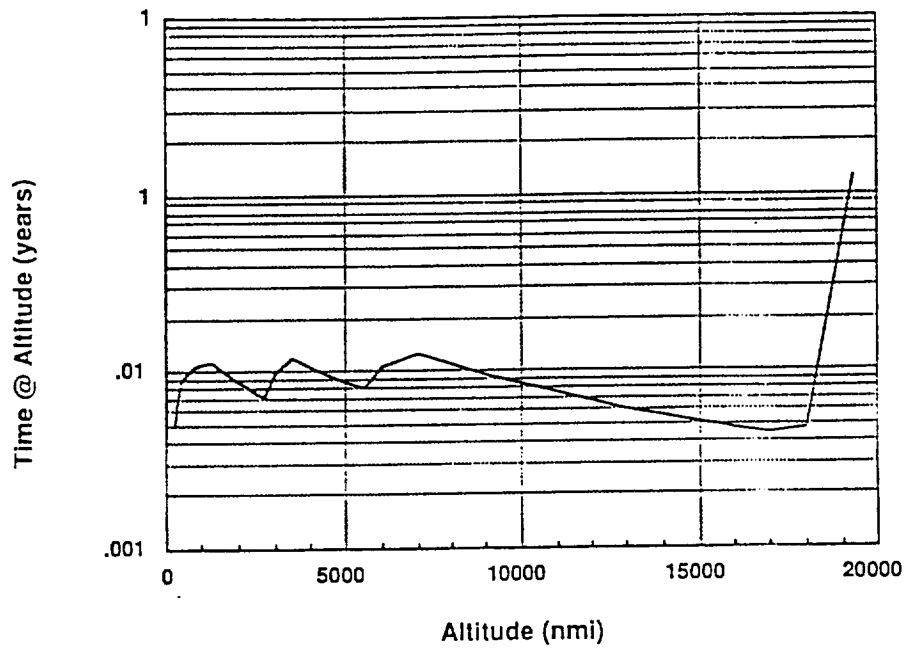

Figure 5: Time at Altitude Flight Profile

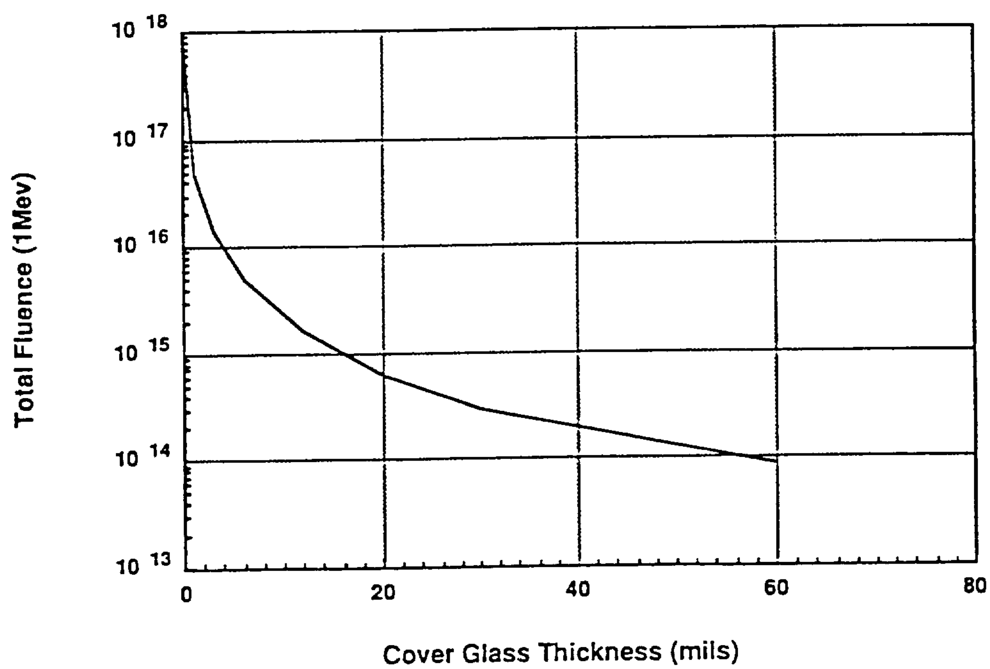

Figure 6: Total Fluence vs Cover Glass Thickness

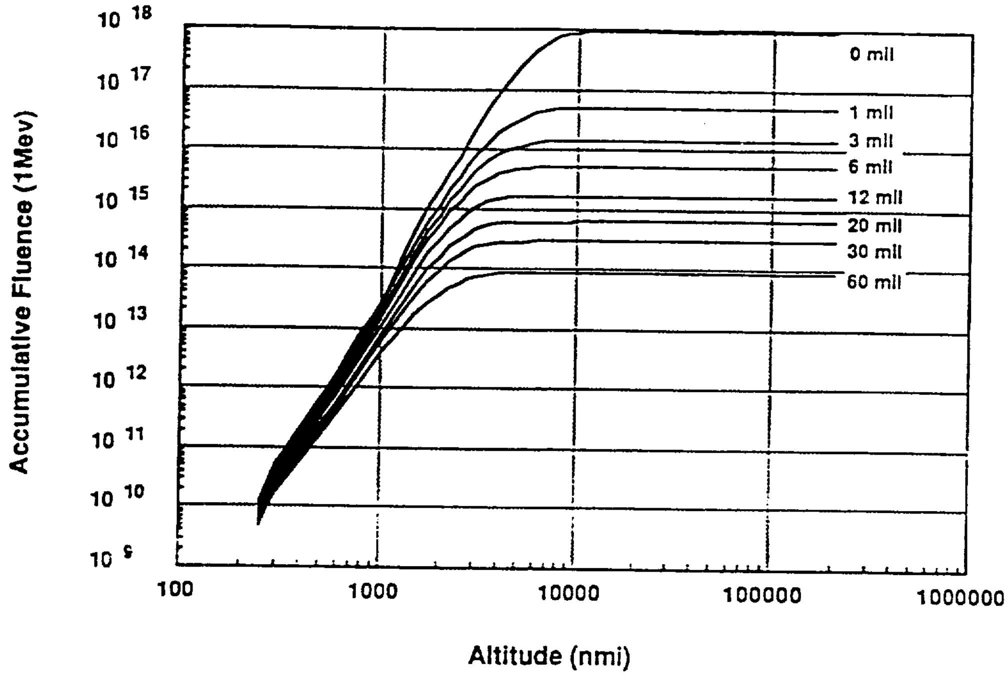

Figure 7: Accumulative Fluence vs Altitude
for Various Cover Glass Thickness
and 30 Degree Inclination

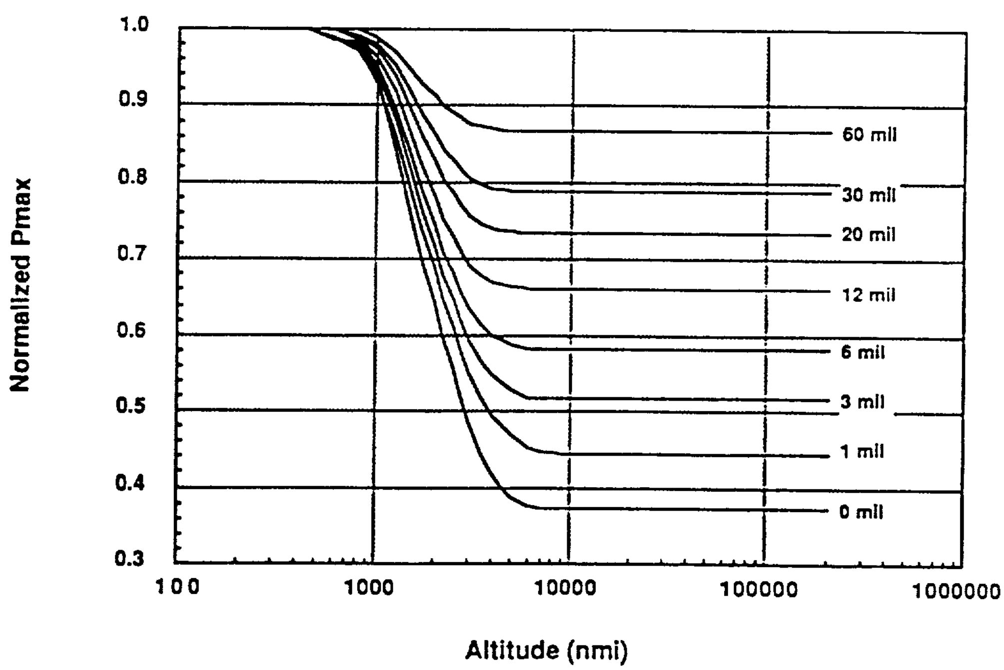

Figure 8: Cell Performance vs Altitude
for Si at 30 Degree Inclination
Infinite Back Shield

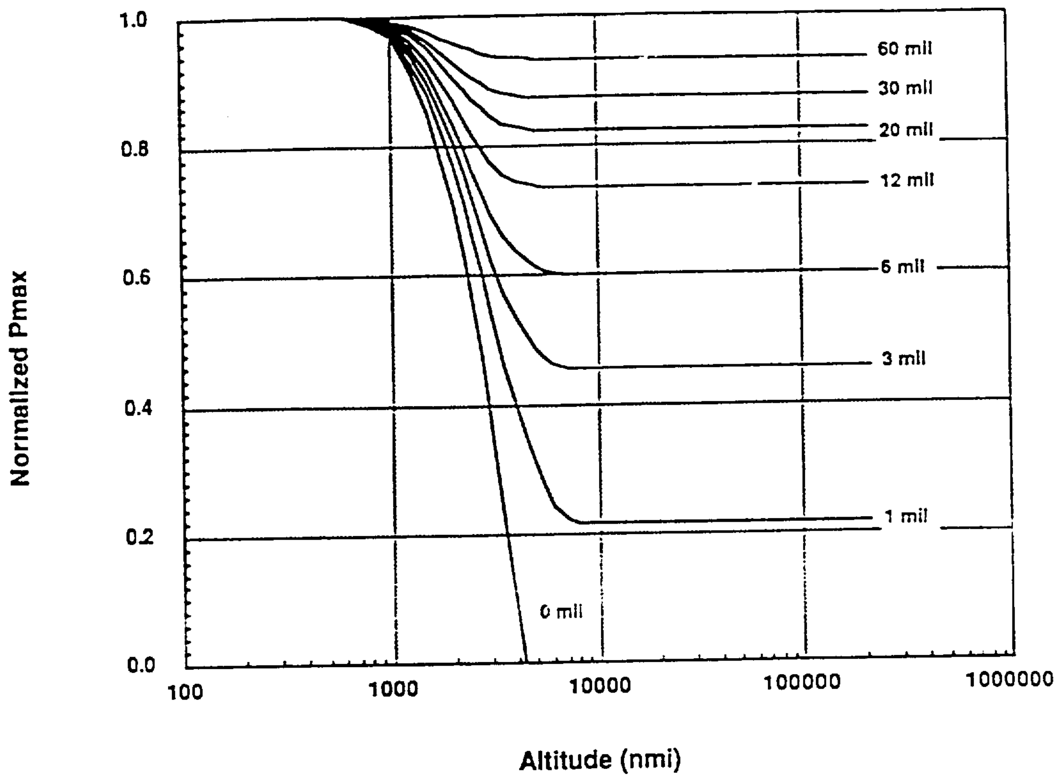

Figure 9: Cell Performance vs Altitude
for GaAs/Ge at 30 Degree Inclination
Infinite Back Shield

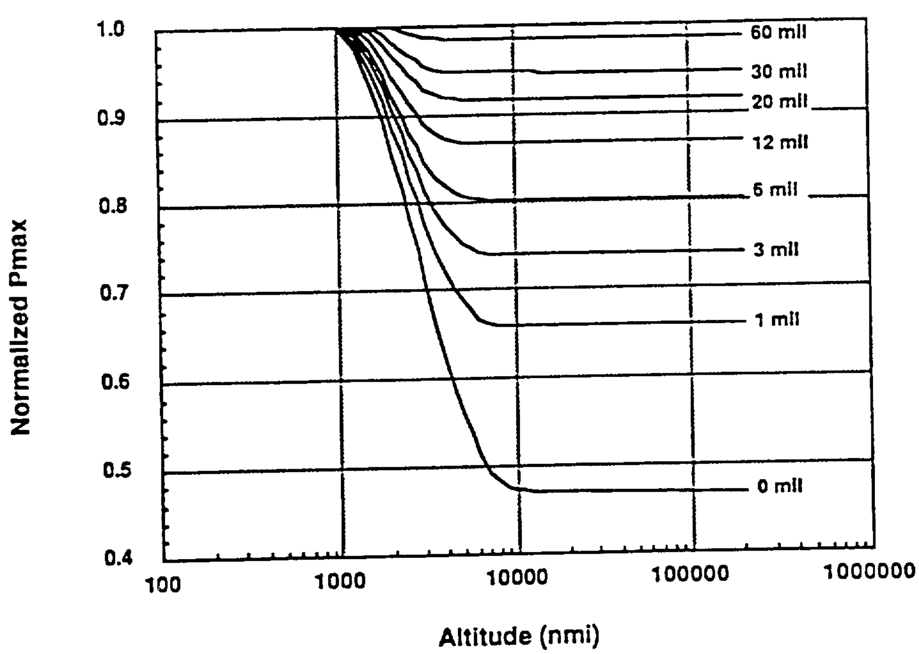

Figure 10: Cell Performance vs Altitude
for InP at 30 Degree Inclination
Infinite Back Shield

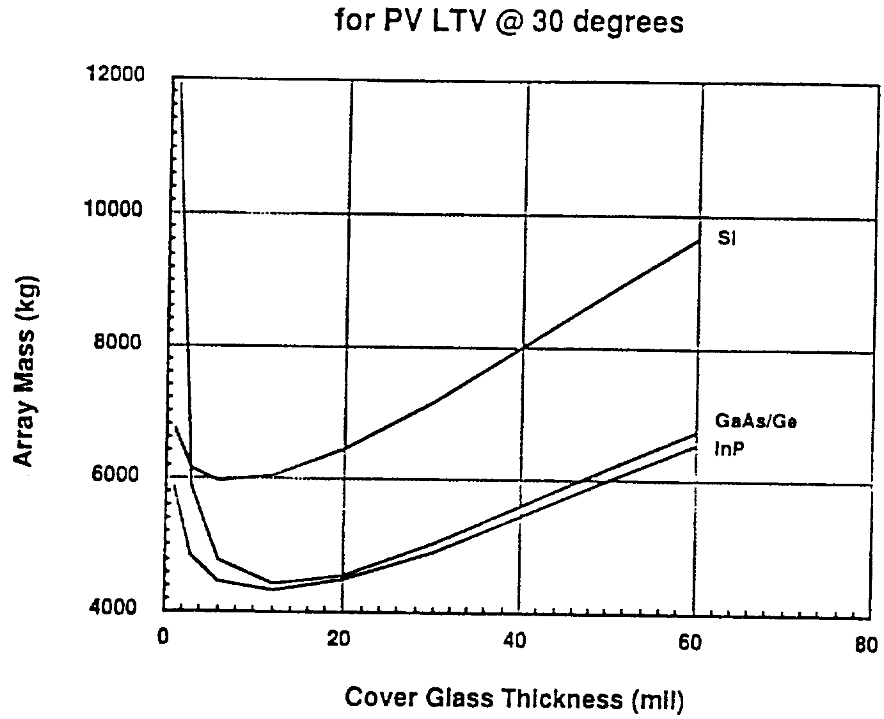

Figure 11: Array Mass vs Cover Glass Thickness

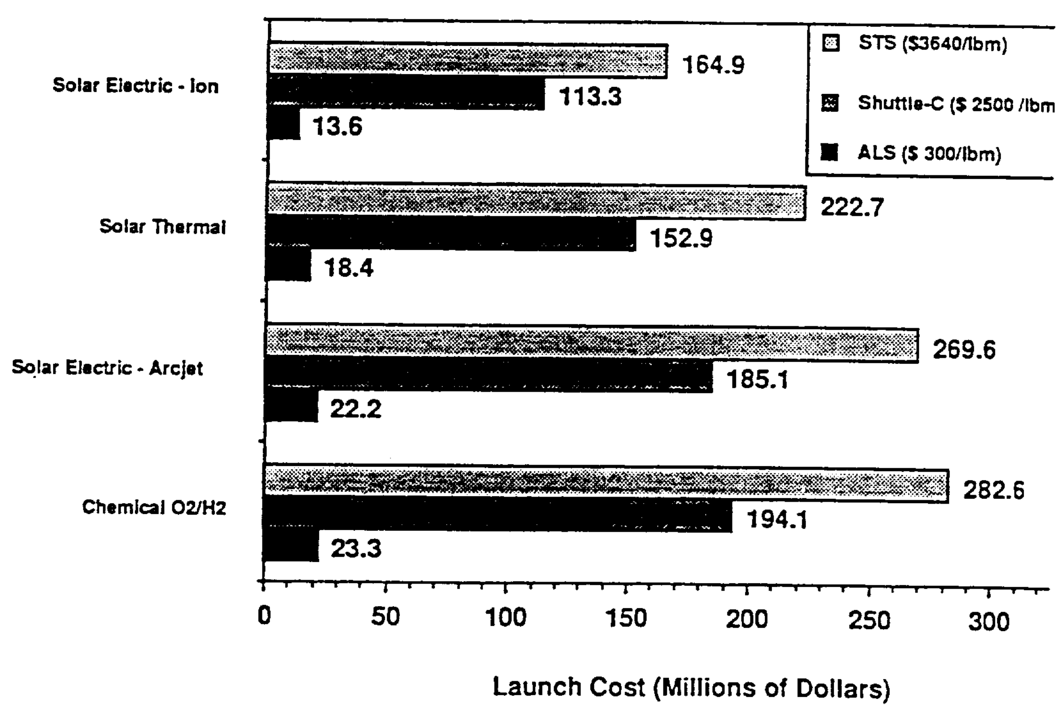

Figure 12: Launch Cost Comparison
for Representative LTV's