(NASA-TM-84989) INTERNATIONAL ULTRAVIOLET EXPLORER SOLAR ARRAY POWER DEGRADATION (NASA) 77 p HC A05/MF A01 CSCL 22B

N83-30500

Unclas
G3/15 13184

NASA
Technical Memorandum 84989

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JANUARY 1983

National Aeronautics and
Space Administration

Goddard Space Flight Center
Greenbelt, Maryland 20771

TM 84989

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CONTENTS

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INTRODUCTION

The International Ultraviolet Explorer (IUE) has been in geosynchronous orbit since January 26, 1978. Its mission has been to perform ultraviolet (UV) spectroscopy with stars using a 45 cm UV telescope with an echelle spectrograph.[1,2] IUE experiments have made many contributions to state-of-the-art UV astronomy.[3,4] Therefore, it is desirable to extend operation of the spacecraft beyond its life design goal (3-5 years). This is made possible because the array continues to produce much more power than is required at most observatory positions.[5] Preflight calculations[6] which predicted the IUE solar array output for up to three years of flight are now obsolete. The available IUE array power is calculated in this work for the initial life requirement of three years. The calculation is normalized to flight data at three years. Then the normalized power calculation is performed for life goals up to ten years of flight.

ARRAY DESIGN

The IUE solar array has two paddles, as illustrated in Figure 1. Each paddle has three panels (one central panel, 70.5 cm X 54.8 cm, and two lateral panels, 70.5 cm X 67.8 cm). The lateral panels are attached to opposite sides of the central panel with each lateral panel plane making a 45° angle with the central panel plane. The plane of each array panel is perpendicular to the XZ plane of the spacecraft. Thus, as the orientation of the spacecraft is controlled such that the sun is always in the XZ plane, the position of the sun with respect to all six array panels is defined by only one coordinate (angle β). Values of β are confined to the range 0° to 135° because the telescope, coaxial to the +X axis of the spacecraft, can not be pointed to within 45° of the sunline.

Each array panel has honeycomb-type construction. There are 4980 2 cm X 2 cm, n/p silicon solar cells bonded to the array structure with silicon adhesive. The cells are .02 cm thick with a 1 Ω-cm resistivity. Cerium doped covers, .01 cm thick, provided protection to the cells against immediate catastrophic radiation damage. The cells are wired with welded stress-relief, silver-on-molybdenum interconnects such that each central panel has 69 series cells per string by 20 parallel strings; and each lateral panel has 75 series cells per string by 24 parallel strings. The operating voltage of the average cell on each central and lateral panel is 423 mV and 389 mV, respectively. This leads to 28 volts across each parallel string at the spacecraft bus line after substracting interface losses. The power supplied by each central and lateral panel is 28 volts · $20I_C$ and 28 volts · $24I_L$; where, I_C and I_L are the currents generated by the average cell on the central and lateral panels, respectively. Hence, to determine the available power output for the IUE solar array, the average current-voltage (I-V) characteristics of typical IUE solar cells are evaluated in the following sections as a function of several prevailing variables (namely, illumination, temperature and radiation damage).

SOLAR ILLUMINATION AND ARRAY TEMPERATURE

The position of the sun with respect to the array is described by the angle β. The sunline normal to the surface of the central panels occurs at β=67.5°. Thus, the view factor for the central panel is cos (β-67.5°). Consequently, the view factors for the lower lateral panels and the upper

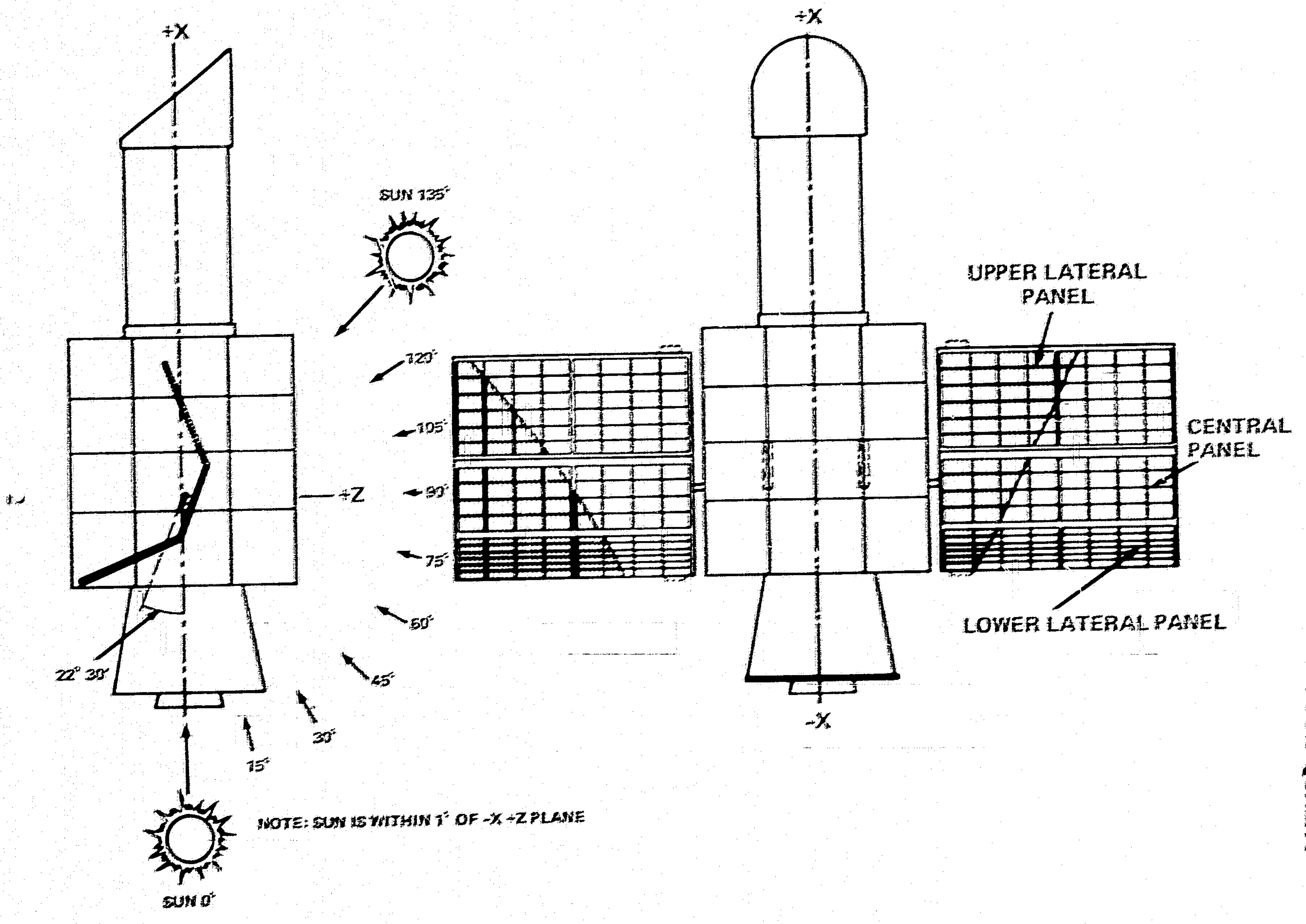

Figure 1. The International Ultraviolet Explorer.[1]

lateral panels are cos (β-112.5°) and cos (β-22.5°), respectively, as a ± 45° rotation is required to displace a lateral panel to the plane of the central panels. The cosine law does not describe the complete dependence of the solar illumination, because of the variation of the earth's distance from the sun between summer and winter solstices. The best and worst case correction factors are 1.035 (winter) and .965 (summer). A re-examination of Figure 1 reveals an additional correction to the cosine view factor. No array panel has its normal passing through the spacecraft center of coordinates from which the angle β is measured. However, this error is negligible because of the comparably large distance to the sun.

At normal incidence to a given IUE array panel, the solar illumination is 1 solar constant which has been shown[7] to be approximately 135.3 mW/m². That solar energy which is not converted to electrical energy is dissipated as heat. As the sun is the primary source of heat and the cell illumination depends on β, so does the array temperature depend on β. Preflight calculations[8] were performed to determine how the IUE array temperature varies with β. The predicted temperature profiles at the three year life requirement are displayed in Figure 2. This thermal study was based on a combination of two models. A radiative model considered reflections and emissions from all viewing surfaces (panels, paddle support arms and satellite body) in addition to direct solar illumination. A conductive model considered heat transfer across the honeycomb panels, the silicon cells and the cell interconnects. The calculations also predicted a minimum array temperature of −155°C to −165°C during IUE eclipses, 57 min to 71 min, respectively.

Two platinum resistors were mounted on each IUE array panel to monitor solar cell temperature. The array with its platinum thermometers were subjected to preflight thermal cycling between −150°C and +60°C. The performance of the resistors was unreliable with two failing only during cold phases and three failing during hot and cold phases before the completion of forty cycles. As the array temperature sensors are not flight essential, no defective platinum thermometer was replaced. Six of the twelve sensors were connected to IUE telemetry. As previously reported,[9] two of the six platinum resistors failed during the first year of flight. As of three years flight time, the remaining four temperature sensors (one lower panel, one upper panel and both central panels) operated reliably except for a few erroneous readings during cold phases. A temperature reading from each sensor as well as a β angle reading is acquired each hour. These data acquired at 3 years ±30 days are shown in Figures 3, 4 and 5 for the central, lower and upper array panels, respectively. In each case a least-squares routine[10] was applied to the data (panel temperature versus β angle) to determine the best second order fit. As shown in a preflight study,[11] the uncertainty in the temperature measurement is ±3.7°C. Thus, the best case temperatures and worst case temperatures are obtained by shifting the above curves by +3.7°C and −3.7°C, respectively.

IRRADIATION DOSAGE

A study has been performed to determine the IUE radiation environment.[12] The IUE orbit (period, 24 hrs; perigee, 25235 Km; apogee, 46350 Km; and inclination, 29°) was integrated over the then most current space radiation models to estimate the charge particle fluences for a mission duration of three years. In the case of trapped electrons, fluences were calculated using the AEI7-HI model[13] for outer zone electrons; IUE never enters the inner zone. This model is an upper limit

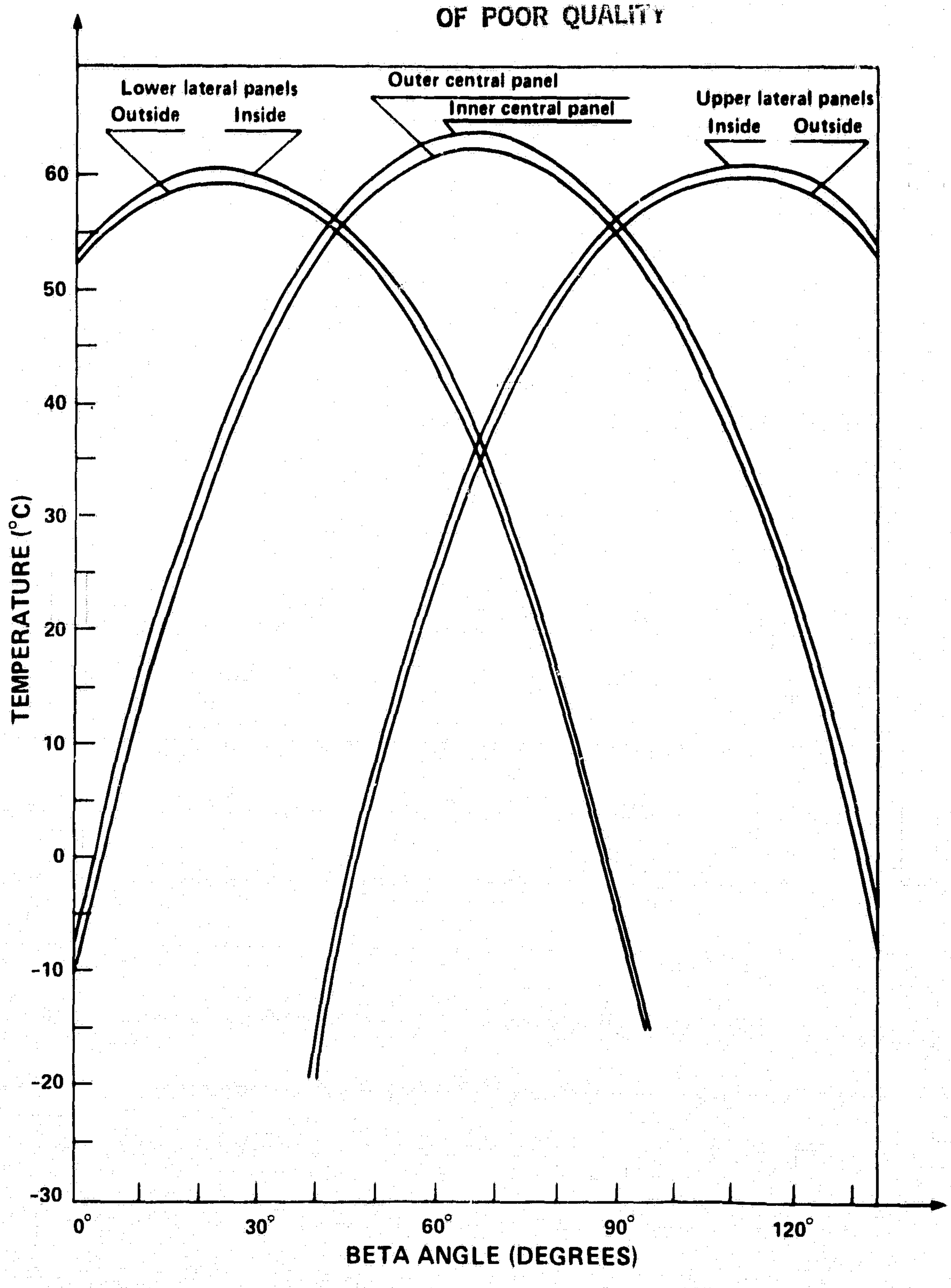

Figure 2. Average Panel Temperature Versus Sun Position.[8]

	COEFFICIENT	99 % CONFIDENCE INTERVAL LOWER LIMIT	UPPER LIMIT
'CONSTANT'	-12.18705	-14.95155	-9.42255
X^1	2.13056	2.04797	2.21315
X^2	-.01563	-.01617	-.01509

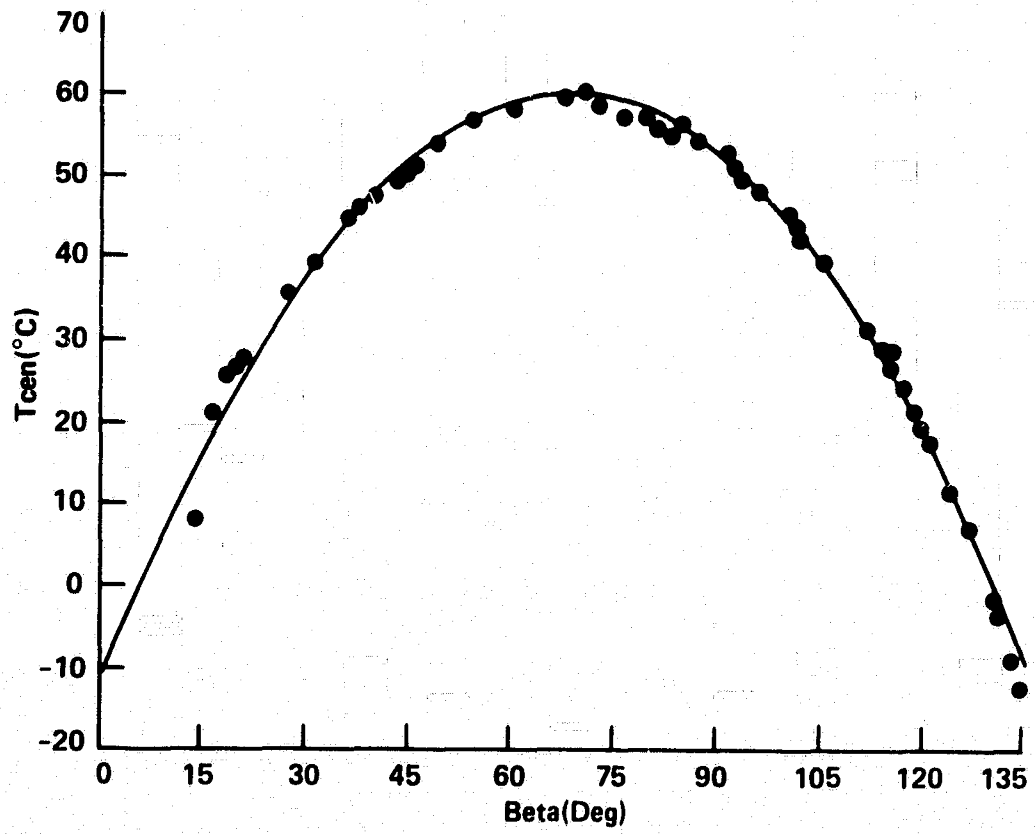

Figure 3. Central Panel Temperature versus Beta Angle.

	COEFFICIENT	99 % CONFIDENCE INTERVAL LOWER LIMIT	UPPER LIMIT
'CONSTANT'	37.41513	33.33397	41.49629
X^1	1.10256	.91488	1.29023
X^2	-.01848	-.02021	-.01676

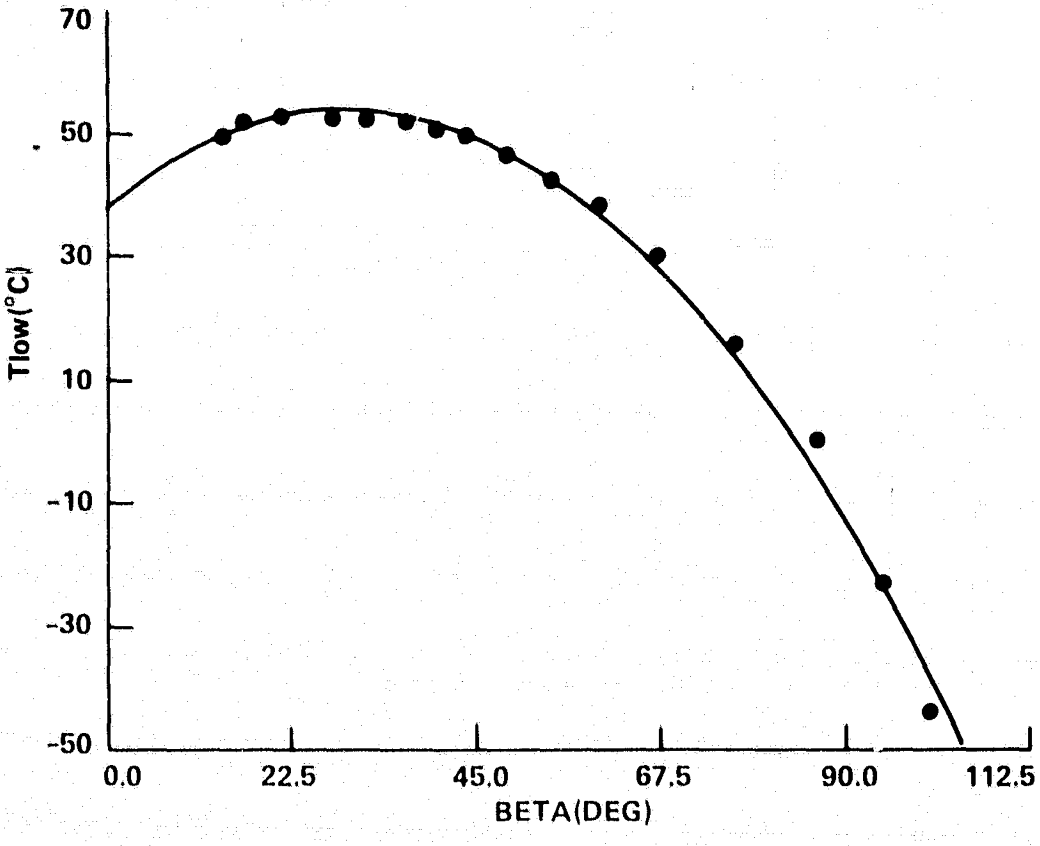

Figure 4. Lower Panel Temperature versus Beta Angle.

	COEFFICIENT	99 % CONFIDENCE INTERVAL LOWER LIMIT	UPPER LIMIT
'CONSTANT'	-126.39350	-134.78038	-118.00661
X^1	3.51306	3.31088	3.71523
X^2	-0.01652	-0.01768	-0.01536

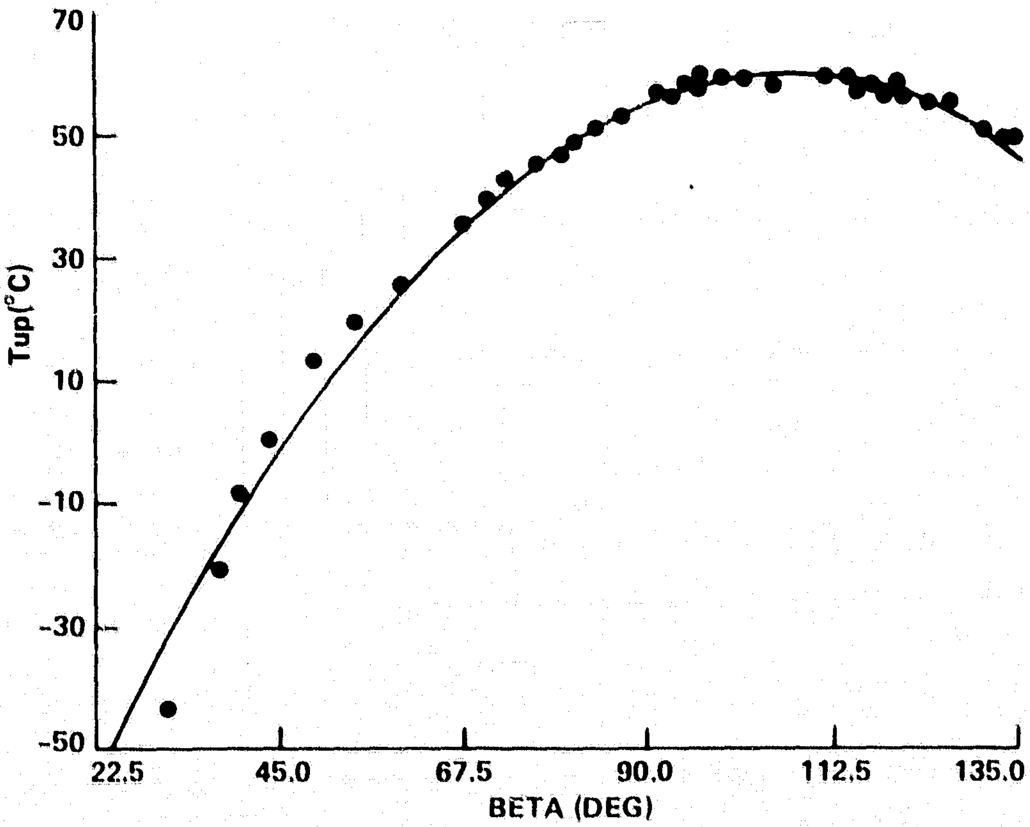

Figure 5. Upper Panel Temperature versus Beta Angle.

(worst case) estimate. The results are given in Table 1. These data are reduced by one half to obtain a lower limit (best case) estimate. Fluences for trapped protons were calculated using the solar maximum version of the AP8 model.[14] The results are given in Table 2 for numbers of anomalously large solar events predicted with a confidence level above 80 percent. The best and worst cases correspond to two and five events, respectively.

Much is known about the degradation of solar cells due to irradiation with monoenergetic unidirectional charged particles. However, the space radiation environment of IUE, as well as other spacecrafts, consists of a spectrum of omnidirectional charged particles. Hence, multienergetic omnidirectional space radiation fluences were converted to an equivalent 1 Mev normal incidence electron fluence using the procedure, as interpreted from the literature,[15] given below.

Step 1 Calculate the 1 Mev electron fluence $\psi^{(t)}_{1 Mev\, e}$ at normal incidence upon a cell of shield thickness t that produces radiation damage equivalent to that produced by the multienergetic space electron fluence $\phi_e(E=0) \cdots \phi_e(E=\infty)$.

For all I-V parameters

$$\psi^{(t)}_{1 Mev\, e} = \sum_{E=0}^{\infty} [\phi_e(>E-dE/2) - \phi_e(>E+dE/2)] \cdot D_e(E,t)$$

where $D_e(o,t) \cdots D_e(\infty,t)$ are damage coefficients interpolated from Table 3.

Table 1
Electrons Incident Upon IUE[12]

ENERGY (> Mev)	AVERAGE INTEGRAL FLUX (ELECTRONS/cm^2 · DAY)*
.5	2.076E 11
1.0	2.185E 10
1.5	2.109E 10
2.0	7.303E 09
2.5	3.147E 09
3.0	1.376E 09
3.5	8.472E 08
4.0	5.217E 08
4.5	2.217E 08
5.0	1.215E 08
5.5	3.825E 07
6.0	1.204E 07
6.5	1.488E 06
7.0	1.000E 00

*MULTIPLY TIMES 1096 DAYS

Table 2
Protons Incident Upon IUE[12]

ENERGY (> Mev)	TOTAL NO. OF PARTICLES/CM² FOR A MISSION DURATION OF τ = 3 YEARS			
	CONFIDENCE LEVEL Q(%)*			
	80-91	92-96	97-98	99
	NO. OF ANOMALOUSLY LARGE EVENTS PREDICTED FOR GIVEN τ & Q			
	(2)	(3)	(4)	(5)
10.0	3.360E 10	5.040E 10	6.720E 10	8.400E 10
20.0	2.304E 10	3.456E 10	4.608E 10	5.760E 10
30.0	1.580E 10	2.370E 10	3.160E 10	3.950E 10
40.0	1.083E 10	1.675E 10	2.167E 10	2.708E 10
50.0	7.428E 09	1.114E 10	1.486E 10	1.857E 10
60.0	5.094E 09	7.641E 09	1.019E 10	1.274E 10
70.0	3.492E 09	5.238E 09	6.984E 09	8.730E 09
80.0	2.394E 09	3.591E 09	4.788E 09	5.985E 09
90.0	1.642E 09	2.463E 09	3.284E 09	4.105E 09
100.0	1.126E 09	1.689E 09	2.252E 09	2.814E 09

*Q DENOTES THE DEGREE OF CONFIDENCE ONE WISHES TO ASSIGN TO THE RESULTS, NAMELY THAT FOR THE SPECIFIED MISSION DURATION THE CALCULATED FLUENCES ARE THE SMALLEST VALUES WHICH WILL NOT BE EXCEEDED BY ACTUALLY ENCOUNTERED INTENSITIES.

Step 2 Calculate the 10 Mev proton fluence $\psi^{(t)}_{10\text{Mev }p}$ at normal incidence upon a cell of shield thickness t that produces radiation damage equivalent to that produced by the multienegetic space proton fluence $\phi_p(E{=}0) \cdots \phi_p(E{=}\infty)$.

For I-V parameter I_{SC}

$$\psi^{(t)}_{10\text{Mev }p} = \sum_{E=0}^{\infty} [\phi_p(>E-dE/2)-\phi_p(>E+dE/2)] \cdot D_p^{SC}(E,t)$$

where $D_p^{SC}(o,t) \cdots D_p^{SC}\,\infty,t)$ are damage coefficients interpolated from Table 4.

For I-V parameters V_{OC} & P_{MAX}

$$\psi^{(t)}_{10\text{Mev }p} = \sum_{e=0}^{\infty} [\Phi_p(>E-dE/2)-+_p(>E+dE/2)] \cdot D_p^{OC}\,E,t)$$

where $D_p^{OC}(o,t) \cdots D_p^{OC}(\infty,t)$ are damage coefficients from Table 5.

Table 3
Electron Damage Coefficients[15]

ENERGY (Mev)	SHIELD THICKNESS (GM/CM²)							
	0	5.59E-3	1.68E-2	3.35E-2	6.71E-2	1.12E-1	1.68E-1	3.35E-1
.150	2.690E-04	3.687E-05	0.	0.	0.	0.	0.	0.
.160	5.000E-04	7.951E-05	0.	0.	0.	0.	0.	0.
.170	8.951E-04	1.620E-04	0.	0.	0.	0.	0.	0.
.180	1.550E-03	3.168E-04	2.227E-05	0.	0.	0.	0.	0.
.190	2.406E-03	5.938E-04	5.228E-05	0.	0.	0.	0.	0.
.200	3.650E-03	1.045E-03	1.143E-04	0.	0.	0.	0.	0.
.220	6.750E-03	2.533E-03	4.375E-04	1.551E-05	0.	0.	0.	0.
.240	1.035E-02	4.924E-03	1.263E-03	8.667E-05	0.	0.	0.	0.
.260	1.450E-02	7.981E-03	2.814E-03	3.609E-04	0.	0.	0.	0.
.280	2.010E-02	1.174E-02	5.052E-03	1.073E-03	0.	0.	0.	0.
.300	2.725E-02	1.668E-02	7.941E-03	2.400E-03	2.828E-05	0.	0.	0.
.320	3.385E-02	2.249E-02	1.156E-02	4.220E-03	1.481E-04	0.	0.	0.
.360	5.004E-02	3.581E-02	2.142E-02	9.858E-03	1.314E-03	0.	0.	0.
.400	7.000E-02	5.255E-02	3.423E-02	1.855E-02	4.311E-03	9.075E-05	0.	0.
.450	9.506E-02	7.562E-02	5.344E-02	3.258E-02	1.106E-02	1.295E-03	0.	0.
.500	1.250E-01	1.023E-01	7.595E-02	5.059E-02	2.146E-02	4.824E-03	7.759E-05	0.
.600	2.000E-01	1.703E-01	1.343E-01	9.816E-02	5.347E-02	2.158E-02	4.315E-03	0.
.700	2.700E-01	2.400E-01	2.004E-01	1.574E-01	9.769E-02	4.926E-02	1.802E-02	0.
.800	3.500E-01	3.166E-01	2.718E-01	2.225E-01	1.527E-01	9.074E-02	4.262E-02	3.097E-04
.900	4.225E-01	3.898E-01	3.438E-01	2.910E-01	2.121E-01	1.385E-01	7.726E-02	4.452E-03
1.000	5.000E-01	4.657E-01	4.169E-01	3.607E-01	2.759E-01	1.934E-01	1.199E-01	1.566E-02
1.200	6.700E-01	6.303E-01	5.733E-01	5.072E-01	4.068E-01	3.081E-01	2.172E-01	5.937E-02
1.400	8.600E-01	8.160E-01	7.515E-01	6.759E-01	5.593E-01	4.419E-01	3.312E-01	1.281E-01
1.600	1.060E+00	1.012E+00	9.405E-01	8.564E-01	7.256E-01	5.916E-01	4.614E-01	2.120E-01
1.800	1.260E+00	1.210E+00	1.136E+00	1.045E+00	9.022E-01	7.521E-01	6.040E-01	3.099E-01
2.000	1.470E+00	1.418E+00	1.339E+00	1.242E+00	1.088E+00	9.245E-01	7.611E-01	4.236E-01
2.250	1.729E+00	1.676E+00	1.592E+00	1.489E+00	1.323E+00	1.145E+00	9.639E-01	5.793E-01
2.500	2.000E+00	1.943E+00	1.854E+00	1.744E+00	1.566E+00	1.374E+00	1.178E+00	7.499E-01
2.750	2.252E+00	2.197E+00	2.108E+00	1.997E+00	1.813E+00	1.611E+00	1.399E+00	9.314E-01
3.000	2.510E+00	2.454E+00	2.362E+00	2.248E+00	2.057E+00	1.847E+00	1.627E+00	1.125E+00
3.250	2.754E+00	2.698E+00	2.606E+00	2.490E+00	2.295E+00	2.078E+00	1.849E+00	1.320E+00
3.500	3.000E+00	2.943E+00	2.850E+00	2.731E+00	2.531E+00	2.309E+00	2.072E+00	1.520E+00
3.750	3.249E+00	3.191E+00	3.096E+00	2.974E+00	2.770E+00	2.541E+00	2.296E+00	1.723E+00
4.000	3.500E+00	3.442E+00	3.344E+00	3.220E+00	3.011E+00	2.775E+00	2.523E+00	1.928E+00
4.500	3.950E+00	3.894E+00	3.798E+00	3.675E+00	3.464E+00	3.223E+00	2.962E+00	2.332E+00
5.000	4.400E+00	4.344E+00	4.247E+00	4.121E+00	3.905E+00	3.659E+00	3.390E+00	2.738E+00
5.500	4.850E+00	4.793E+00	4.695E+00	4.566E+00	4.346E+00	4.093E+00	3.817E+00	3.141E+00
6.000	5.300E+00	5.243E+00	5.143E+00	5.012E+00	4.787E+00	4.528E+00	4.244E+00	3.545E+00
7.000	6.150E+00	6.093E+00	5.992E+00	5.859E+00	5.627E+00	5.358E+00	5.062E+00	4.326E+00
8.000	6.900E+00	6.848E+00	6.753E+00	6.626E+00	6.401E+00	6.138E+00	5.844E+00	5.097E+00
9.000	7.607E+00	7.555E+00	7.462E+00	7.335E+00	7.112E+00	6.848E+00	6.553E+00	5.801E+00
10.000	8.300E+00	8.249E+00	8.156E+00	8.029E+00	7.804E+00	7.539E+00	7.241E+00	6.479E+00
15.000	1.060E+01	1.056E+01	1.049E+01	1.039E+01	1.020E+01	9.981E+00	9.725E+00	9.047E+00
20.000	1.230E+01	1.227E+01	1.221E+01	1.213E+01	1.197E+01	1.177E+01	1.155E+01	1.095E+01
25.000	1.360E+01	1.357E+01	1.352E+01	1.344E+01	1.329E+01	1.311E+01	1.290E+01	1.233E+01
30.000	1.470E+01	1.467E+01	1.462E+01	1.455E+01	1.442E+01	1.425E+01	1.405E+01	1.352E+01
40.000	1.650E+01	1.648E+01	1.643E+01	1.637E+01	1.625E+01	1.610E+01	1.593E+01	1.544E+01

Table 4
Proton Damage Coefficients for I_{SC} [15]

ENERGY (Mev)	SHIELD THICKNESS (GM/CM²)							
	0	5.59E-3	1.68E-2	3.35E-2	6.71E-2	1.12E-1	1.68E-1	3.35E-1
.100	2.435E-04	0.	0.	0.	0.	0.	0.	0.
.200	3.047E-03	0.	0.	0.	0.	0.	0.	0.
.300	1.374E-02	0.	0.	0.	0.	0.	0.	0.
.400	3.987E-02	0.	0.	0.	0.	0.	0.	0.
.600	1.502E-01	0.	0.	0.	0.	0.	0.	0.
.800	3.243E-01	0.	0.	0.	0.	0.	0.	0.
1.000	5.216E-01	0.	0.	0.	0.	0.	0.	0.
1.200	7.108E-01	0.	0.	0.	0.	0.	0.	0.
1.300	7.890E-01	2.322E-05	0.	0.	0.	0.	0.	0.
1.400	8.549E-01	3.750E-03	0.	0.	0.	0.	0.	0.
1.600	9.532E-01	8.124E-02	0.	0.	0.	0.	0.	0.
1.800	1.010E+00	2.525E-01	0.	0.	0.	0.	0.	0.
2.000	1.039E+00	4.558E-01	0.	0.	0.	0.	0.	0.
2.200	1.048E+00	6.233E-01	0.	0.	0.	0.	0.	0.
2.400	1.041E+00	7.426E-01	0.	0.	0.	0.	0.	0.
2.600	1.023E+00	8.207E-01	1.860E-05	0.	0.	0.	0.	0.
2.800	9.962E-01	8.680E-01	3.925E-02	0.	0.	0.	0.	0.
3.000	9.639E-01	8.912E-01	1.794E-01	0.	0.	0.	0.	0.
3.200	9.286E-01	8.962E-01	3.465E-01	0.	0.	0.	0.	0.
3.400	8.937E-01	8.871E-01	4.807E-01	0.	0.	0.	0.	0.
3.600	8.598E-01	8.697E-01	5.787E-01	0.	0.	0.	0.	0.
3.800	8.273E-01	8.481E-01	6.459E-01	0.	0.	0.	0.	0.
4.000	7.963E-01	8.243E-01	6.879E-01	1.288E-03	0.	0.	0.	0.
4.200	7.723E-01	7.989E-01	7.105E-01	7.227E-02	0.	0.	0.	0.
4.400	7.486E-01	7.734E-01	7.189E-01	2.077E-01	0.	0.	0.	0.
4.600	7.254E-01	7.499E-01	7.184E-01	3.274E-01	0.	0.	0.	0.
4.800	7.029E-01	7.280E-01	7.120E-01	4.191E-01	0.	0.	0.	0.
5.200	6.605E-01	6.866E-01	6.890E-01	5.286E-01	0.	0.	0.	0.
5.600	6.216E-01	6.479E-01	6.613E-01	5.723E-01	0.	0.	0.	0.
6.000	5.867E-01	6.119E-01	6.319E-01	5.839E-01	2.142E-03	0.	0.	0.
6.400	5.585E-01	5.792E-01	6.019E-01	5.793E-01	1.742E-01	0.	0.	0.
6.800	5.339E-01	5.520E-01	5.731E-01	5.664E-01	3.196E-01	0.	0.	0.
7.200	5.128E-01	5.285E-01	5.477E-01	5.491E-01	3.945E-01	0.	0.	0.
7.600	4.947E-01	5.086E-01	5.255E-01	5.299E-01	4.317E-01	0.	0.	0.
8.000	4.786E-01	4.909E-01	5.058E-01	5.118E-01	4.484E-01	0.	0.	0.
9.000	4.476E-01	4.565E-01	4.669E-01	4.724E-01	4.478E-01	2.735E-01	0.	0.
10.000	4.337E-01	4.369E-01	4.401E-01	4.425E-01	4.292E-01	3.537E-01	0.	0.
11.000	4.232E-01	4.245E-01	4.258E-01	4.226E-01	4.101E-01	3.675E-01	2.061E-01	0.
12.000	4.196E-01	4.187E-01	4.155E-01	4.110E-01	3.956E-01	3.649E-01	2.839E-01	0.
13.000	4.185E-01	4.167E-01	4.120E-01	4.040E-01	3.872E-01	3.588E-01	3.062E-01	0.
14.000	4.181E-01	4.159E-01	4.105E-01	4.020E-01	3.828E-01	3.553E-01	3.131E-01	0.
15.000	4.194E-01	4.173E-01	4.104E-01	4.010E-01	3.814E-01	3.538E-01	3.159E-01	0.
16.000	4.214E-01	4.182E-01	4.120E-01	4.025E-01	3.819E-01	3.547E-01	3.187E-01	1.439E-01
18.000	4.192E-01	4.179E-01	4.133E-01	4.054E-01	3.873E-01	3.606E-01	3.269E-01	2.175E-01
20.000	4.172E-01	4.159E-01	4.125E-01	4.055E-01	3.900E-01	3.679E-01	3.379E-01	2.441E-01
22.000	4.144E-01	4.117E-01	4.093E-01	4.047E-01	3.915E-01	3.731E-01	3.473E-01	2.648E-01
24.000	4.094E-01	4.083E-01	4.059E-01	4.010E-01	3.919E-01	3.757E-01	3.457E-01	2.834E-01
26.000	4.049E-01	4.039E-01	4.018E-01	3.985E-01	3.898E-01	3.769E-01	3.591E-01	2.984E-01
28.000	4.000E-01	3.994E-01	3.978E-01	3.939E-01	3.875E-01	3.764E-01	3.613E-01	3.101E-01
30.000	3.935E-01	3.930E-01	3.918E-01	3.896E-01	3.834E-01	3.753E-01	3.625E-01	3.186E-01
34.000	3.784E-01	3.782E-01	3.777E-01	3.767E-01	3.739E-01	3.677E-01	3.600E-01	3.291E-01
38.000	3.664E-01	3.662E-01	3.657E-01	3.650E-01	3.617E-01	3.582E-01	3.529E-01	3.312E-01
42.000	3.532E-01	3.532E-01	3.532E-01	3.530E-01	3.519E-01	3.484E-01	3.446E-01	3.292E-01
46.000	3.399E-01	3.399E-01	3.400E-01	3.400E-01	3.396E-01	3.372E-01	3.349E-01	3.245E-01
50.000	3.272E-01	3.272E-01	3.272E-01	3.273E-01	3.271E-01	3.264E-01	3.250E-01	3.177E-01
55.000	3.125E-01	3.126E-01	3.128E-01	3.130E-01	3.133E-01	3.132E-01	3.126E-01	3.082E-01
60.000	2.988E-01	2.989E-01	2.990E-01	2.992E-01	2.995E-01	2.997E-01	2.993E-01	2.969E-01
65.000	2.844E-01	2.846E-01	2.850E-01	2.855E-01	2.863E-01	2.871E-01	2.875E-01	2.869E-01
70.000	2.710E-01	2.712E-01	2.715E-01	2.720E-01	2.728E-01	2.736E-01	2.743E-01	2.748E-01
80.000	2.474E-01	2.476E-01	2.480E-01	2.485E-01	2.494E-01	2.504E-01	2.514E-01	2.531E-01
90.000	2.245E-01	2.247E-01	2.251E-01	2.256E-01	2.266E-01	2.277E-01	2.289E-01	2.315E-01
100.000	1.997E-01	1.999E-01	2.004E-01	2.010E-01	2.022E-01	2.037E-01	2.052E-01	2.089E-01
130.000	1.492E-01	1.493E-01	1.496E-01	1.500E-01	1.509E-01	1.519E-01	1.530E-01	1.560E-01
160.000	1.183E-01	1.183E-01	1.185E-01	1.188E-01	1.192E-01	1.199E-01	1.206E-01	1.226E-01
200.000	9.215E-02	9.220E-02	9.229E-02	9.242E-02	9.268E-02	9.302E-02	9.344E-02	9.462E-02

Table 5
Proton Damage Coefficients for V_{OC} and P_{MAX} [15]

ENERGY (MeV)	SHIELD THICKNESS (GM/CM²) 0*	5.59E-3	1.68E-2	3.35E-2	6.71E-2	1.12E-1	1.68E-1	3.35E-1
100	5.303E-01	0	0	0	0	0	0	0
200	7.150E-01	0	0	0	0	0	0	0
300	8.673E-01	0	0	0	0	0	0	0
400	9.976E-01	0	0	0	0	0	0	0
600	1.271E+00	0	0	0	0	0	0	0
800	1.546E+00	0	0	0	0	0	0	0
1.000	1.797E+00	0	0	0	0	0	0	0
1.200	1.994E+00	0	0	0	0	0	0	0
1.300	2.087E+00	4.303E-02	0	0	0	0	0	0
1.400	2.160E+00	1.948E-01	0	0	0	0	0	0
1.600	2.290E+00	5.853E-01	0	0	0	0	0	0
1.800	2.412E+00	9.827E-01	0	0	0	0	0	0
2.000	2.502E+00	1.335E+00	0	0	0	0	0	0
2.200	2.569E+00	1.624E+00	0	0	0	0	0	0
2.400	2.615E+00	1.860E+00	0	0	0	0	0	0
2.600	2.645E+00	2.047E+00	1.917E-02	0	0	0	0	0
2.800	2.656E+00	2.191E+00	2.733E-01	0	0	0	0	0
3.000	2.640E+00	2.298E+00	6.097E-01	0	0	0	0	0
3.200	2.597E+00	2.375E+00	9.375E-01	0	0	0	0	0
3.400	2.526E+00	2.416E+00	1.226E+00	0	0	0	0	0
3.600	2.426E+00	2.420E+00	1.468E+00	0	0	0	0	0
3.800	2.307E+00	2.388E+00	1.664E+00	0	0	0	0	0
4.000	2.189E+00	2.320E+00	1.818E+00	4.687E-02	0	0	0	0
4.200	2.054E+00	2.219E+00	1.937E+00	2.866E-01	0	0	0	0
4.400	1.891E+00	2.093E+00	1.998E+00	5.697E-01	0	0	0	0
4.600	1.766E+00	1.967E+00	2.017E+00	8.378E-01	0	0	0	0
4.800	1.650E+00	1.839E+00	1.990E+00	1.054E+00	0	0	0	0
5.200	1.447E+00	1.616E+00	1.833E+00	1.431E+00	0	0	0	0
5.600	1.278E+00	1.478E+00	1.647E+00	1.603E+00	0	0	0	0
6.000	1.136E+00	1.268E+00	1.467E+00	1.584E+00	3.741E-02	0	0	0
6.400	1.020E+00	1.131E+00	1.317E+00	1.468E+00	4.510E-01	0	0	0
6.800	9.237E-01	1.018E+00	1.178E+00	1.339E+00	8.464E-01	0	0	0
7.200	8.440E-01	9.257E-01	1.063E+00	1.218E+00	1.101E+00	0	0	0
7.600	7.775E-01	8.479E-01	9.673E-01	1.109E+00	1.166E+00	0	0	0
8.000	7.204E-01	7.827E-01	8.867E-01	1.013E+00	1.125E+00	3.696E-03	0	0
9.000	6.134E-01	6.880E-01	7.524E-01	8.256E-01	9.573E-01	7.614E-01	0	0
10.000	5.554E-01	5.834E-01	6.303E-01	8.965E-01	7.998E-01	8.473E-01	0	0
11.000	5.169E-01	5.351E-01	5.691E-01	6.105E-01	6.851E-01	7.463E-01	5.746E-01	0
12.000	4.936E-01	5.051E-01	5.264E-01	5.558E-01	6.035E-01	6.557E-01	6.555E-01	0
13.000	4.778E-01	4.859E-01	4.997E-01	5.187E-01	5.493E-01	5.830E-01	6.044E-01	0
14.000	4.663E-01	4.727E-01	4.818E-01	4.934E-01	5.121E-01	5.320E-01	5.496E-01	0
15.000	4.594E-01	4.637E-01	4.688E-01	4.755E-01	4.867E-01	4.961E-01	5.047E-01	0
16.000	4.548E-01	4.572E-01	4.606E-01	4.642E-01	4.685E-01	4.713E-01	4.719E-01	3.775E-01
18.000	4.433E-01	4.458E-01	4.480E-01	4.493E-01	4.478E-01	4.419E-01	4.327E-01	3.956E-01
20.000	4.352E-01	4.367E-01	4.387E-01	4.379E-01	4.343E-01	4.269E-01	4.142E-01	3.698E-01
22.000	4.286E-01	4.278E-01	4.290E-01	4.293E-01	4.250E-01	4.172E-01	4.041E-01	3.569E-01
24.000	4.211E-01	4.211E-01	4.213E-01	4.203E-01	4.176E-01	4.097E-01	3.981E-01	3.530E-01
26.000	4.146E-01	4.144E-01	4.141E-01	4.137E-01	4.102E-01	4.035E-01	3.931E-01	3.524E-01
28.000	4.081E-01	4.081E-01	4.079E-01	4.063E-01	4.040E-01	3.978E-01	3.884E-01	3.527E-01
30.000	4.004E-01	4.005E-01	4.008E-01	3.998E-01	3.969E-01	3.926E-01	3.843E-01	3.530E-01
34.000	3.836E-01	3.848E-01	3.840E-01	3.839E-01	3.831E-01	3.797E-01	3.749E-01	3.520E-01
38.000	3.703E-01	3.704E-01	3.704E-01	3.703E-01	3.686E-01	3.669E-01	3.636E-01	3.473E-01
42.000	3.564E-01	3.567E-01	3.569E-01	3.572E-01	3.571E-01	3.549E-01	3.526E-01	3.409E-01
46.000	3.426E-01	3.426E-01	3.429E-01	3.433E-01	3.436E-01	3.421E-01	3.409E-01	3.334E-01
50.000	3.296E-01	3.296E-01	3.298E-01	3.301E-01	3.304E-01	3.303E-01	3.297E-01	1.248E-01
55.000	3.145E-01	3.145E-01	3.147E-01	3.151E-01	3.158E-01	3.161E-01	3.161E-01	3.132E-01
60.000	3.005E-01	3.006E-01	3.007E-01	3.010E-01	3.016E-01	3.020E-01	3.022E-01	3.007E-01
65.000	2.859E-01	2.861E-01	2.865E-01	2.870E-01	2.880E-01	2.890E-01	2.897E-01	2.899E-01
70.000	2.724E-01	2.726E-01	2.729E-01	2.733E-01	2.743E-01	2.753E-01	2.761E-01	2.723E-01
80.000	2.481E-01	2.483E-01	2.487E-01	2.492E-01	2.501E-01	2.512E-01	2.523E-01	2.543E-01
90.000	2.249E-01	2.251E-01	2.258E-01	2.260E-01	2.270E-01	2.281E-01	2.294E-01	2.320E-01
100.000	1.999E-01	2.001E-01	2.006E-01	2.013E-01	2.025E-01	2.039E-01	2.055E-01	2.092E-01
130.000	1.497E-01	1.493E-01	1.496E-01	1.500E-01	1.509E-01	1.519E-01	1.530E-01	1.560E-01
160.000	1.183E-01	1.183E-01	1.188E-01	1.188E-01	1.192E-01	1.199E-01	1.206E-01	1.226E-01
200.000	9.218E-02	9.220E-02	9.229E-02	9.242E-02	9.268E-02	9.302E-02	9.344E-02	9.462E-02

Step 3 Calculate the 1 Mev electron fluence $\phi^{(t)}_{1Mev}$ at normal incidence upon a cell of shield thickness t that produces radiation damage equivilent to that produced by the spectrum of all space charged particles

For I-V parameter I_{SC}

$$\phi(t)^{SC}_{1Mev\,e} = \psi(t)_{1Mev\,e} + 3000 \cdot \psi(t)_{10\,Mev\,p}$$

For I-V parameters V_{OC} & P_{MAX}

$$\phi(t)^{OC}_{1Mev\,e} = \psi(t)_{1Mev\,e} + 3000 \cdot \psi(t)^{OC}_{10Mev\,e}$$

The damage coefficients given in Tables 3, 4 and 5 are for cells with infinite back shielding. In the case of the IUE solar array, as well as other spacecraft arrays, exposure to radiation from the rear must also be considered. This leads to an effective damage coefficient that is the sum of the damage coefficients for the front and rear shield thicknesses. The cell shielding for the IUE array is illustrated in Figure 6. The front and rear shield thicknesses for which damage coefficients were interpolated are .023 g/cm² and .171 g/cm², respectively. The resulting damage coefficients are given in Tables 6, 7 and 8.

A computer program (Appendix A) has been written to calculate the net equivalent 1 Mev electron fluence following the procedure outlined above. The resulting dosages to which the IUE solar array was exposed after three years are 1.32E+14 1 Mev e/cm² for I_{SC} (best case), 2.97E+14 1 Mev e/cm² for I_{SC} (worst case), 1.41E+14 1 Mev e/cm² for V_{OC} & P_{MAX} (best case) and 3.21E+14 1 Mev e/cm² for V_{OC} & P_{MAX} (worst case).

CELL I-V CHARACTERISTICS

Preflight experiments[16] were performed with typical IUE solar cells to determine the I-V parameters of the average cell. The I-V curves of 500 cells were measured at several cell temperatures. In each case, the illumination was fixed at 1 solar constant as simulated by a standard laboratory source. These cells had not been subjected to any radiation damage. The average curve for several cell temperatures is displayed in Figure 7. The I-V parameters at 25°C are I_{SC} = 140 mA, V_{OC} = 596 mV, P_{MAX} = 65 mW, V_{MP} = 500 mV and I_{MP} = 130 mA. These are taken as the best case values. The worst case I-V parameters at 25°C are I_{SC} = 137 mA, V_{OC} = 596 mV, P_{MAX} = 63.5 mW, V_{MP} = 500 mV and I_{MP} = 127 mA. The 3 mA loss in I_{SC} and I_{MP} was estimated by considering production line variations among the 500 cells.

The degradation of an I-V parameter Y due to an irradiation dosage ϕ is generally approximated by an equation of the following form.[18]

$$Y(\phi) = Y(o) - C \cdot \text{Log}\,(1 + \phi/\phi_C)$$

where ϕ_C is an arbitrary critical fluence and C is the corresponding coefficient. As used in this work,

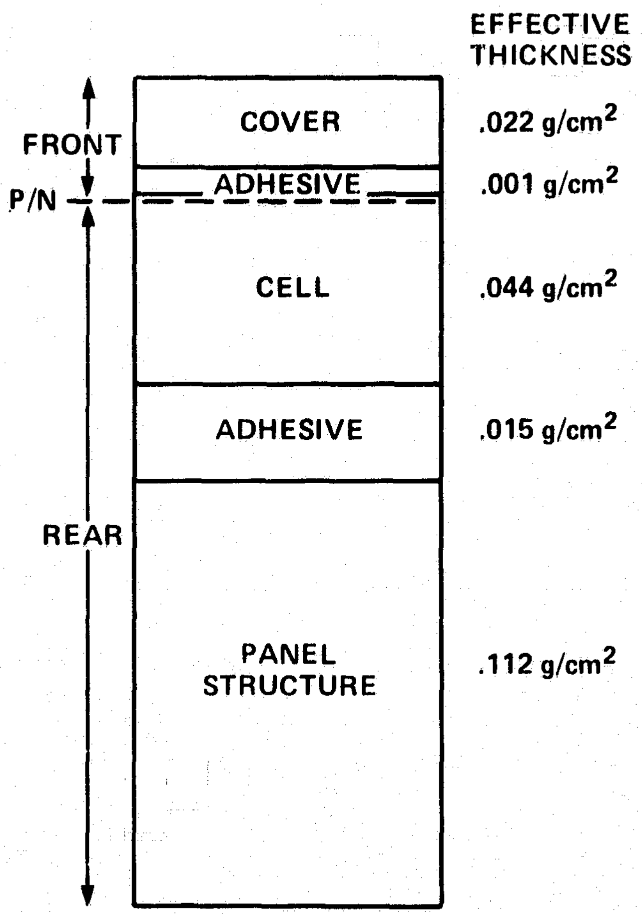

Figure 6. Cell Shielding for IUE Solar Array.

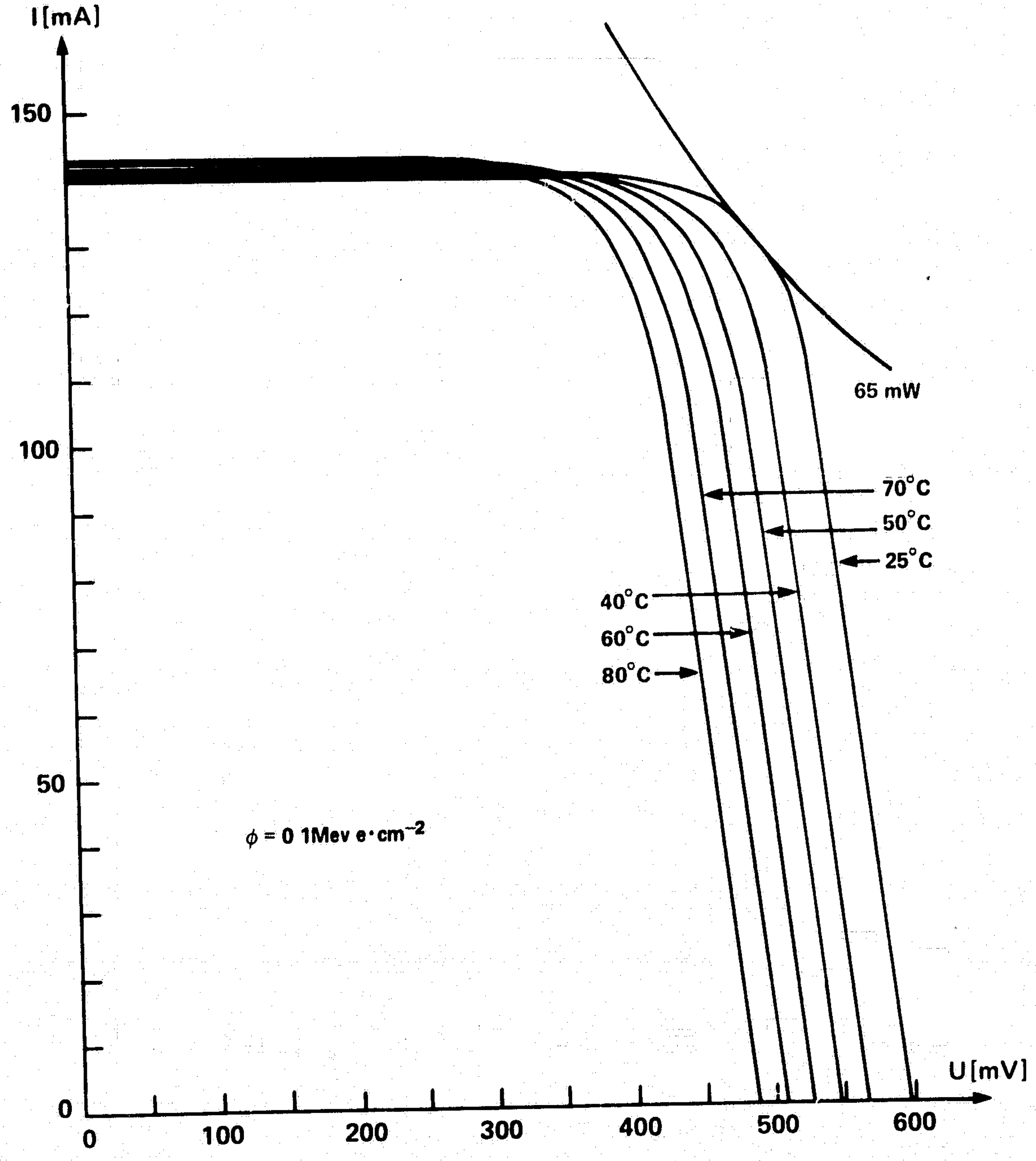

Figure 7. Average I-V characteristics of typical IUE cells at BOL.[16]

Table 6
Electron Damage Coefficients for the Average IUE Solar Cell.

ENERGY (Mev)	FRONT DAMAGE COEFFICIENTS	REAR DAMAGE COEFFICIENTS	NET DAMAGE COEFFICIENTS
.75	.219	.0298	.249
1.25	.592	.243	.835
1.75	1.05	.563	1.61
2.25	1.55	.957	2.51
2.75	2.07	1.39	3.46
3.25	2.56	1.84	4.40
3.75	3.05	2.29	5.34
4.25	3.53	2.73	6.26
4.75	3.98	3.16	7.14
5.25	4.42	3.59	8.01
5.75	4.87	4.02	8.89
6.25	5.31	4.44	9.75
6.75	5.73	4.84	10.57

Table 7
Proton Damage Coefficients for I_{SC} of the Average IUE Solar Cell.

ENERGY (Mev)	FRONT DAMAGE COEFFICIENTS	REAR DAMAGE COEFFICIENTS	NET DAMAGE COEFFICIENTS
15	.407	.310	.717
25	.402	.356	.758
35	.374	.358	.732
45	.343	.337	.680
55	.313	.313	.626
65	.285	.287	.572
75	.260	.263	.523
85	.237	.240	.477
95	.213	.217	.430

Table 8
Proton Damage Coefficients for V_{OC} and P_{MAX} of the Average IUE Solar Cell.

ENERGY (Mev)	FRONT DAMAGE COEFFICIENTS	REAR DAMAGE COEFFICIENTS	NET DAMAGE COEFFICIENTS
15	.471	.496	.967
25	.417	.395	.812
35	.381	.372	.753
45	.347	.344	.691
55	.315	.316	.631
65	.287	.290	.577
75	.261	.264	.525
85	.237	.241	.478
95	.213	.218	.431

the critical fluence is that equivalent 1 Mev electron fluence at normal incidence upon the cell which degrades the I-V parameter to 90 % of its value before irradiation. Data have been previously assembled[15] as a function of cell thickness, that characterizes I-V degradation due to 1 Mev electron irradiation of 2 Ω-cm and 10 Ω-cm. From these data, shown in Figures 8-15, the value of ϕ_C was found for each I-V parameter of the typical IUE cell (1 Ω-cm resistivity and .02 cm thick) by interpolation. At a reference temperature of 30°C, the results for the best case are:

$I_{SC}(\phi) = 140.34$ mA–46.62 mA · Log (1 + ϕ/7.75E+13 1 Mev e/cm²)
$V_{OC}(\phi) = 586.10$ mV–194.70 mV · Log (1 + ϕ/7.50E+14 1 Mev e/cm²)
$P_{MAX}(\phi) = 64.04$ mW–21.27 mW · Log (1 + ϕ/4.70E+13 1 Mev e/cm²)
$V_{MP}(\phi) = 490.32$ mV–162.88 mV · Log (1 + ϕ/9.00E+14 1 Mev e/cm²)
$I_{MP}(\phi) = P_{MAX}(\phi/V_{MP}(\phi)$

The worst case degradation equations are:

$I_{SC}(\phi) = 137.34$ mA–45.62 mA · Log (1 + ϕ/7.75E+13 1 Mev e/cm²)
$V_{OC}(\phi) = 586.10$ mV–194.70 mV · Log (1 + ϕ/7.50E+14 1 Mev e/cm²)
$P_{MAX}(\phi) = 62.54$ mW–20.78 mW · Log (1 + ϕ/4.70E+13 1 Mev e/cm²)
$V_{MP}(\phi) = 490.32$ mV–162.88 mV · Log (1 + ϕ/9.00E+14 1 Mev e/cm²)
$I_{MP}(\phi) = P_{MAX}(\phi)/V_{MP}(\phi)$

Substitution of the previously calculated IUE irradiation dosages into these degradation equations yields the I-V parameters for the average IUE solar cell after 3 years in flight. The respective best and worst case results are 120.24 mA and 106.12 mA for I_{SC}, 571.52 mV and 555.97 mV for V_{OC}, 51.22 mW and 43.97 mW for P_{MAX} and 480.01 mV and 468.74 mV for V_{MP}. These values, however, are valid only when the cell temperature is 30°C.

The variation of each I-V parameter Y with cell temperature T is generally given by an ex-

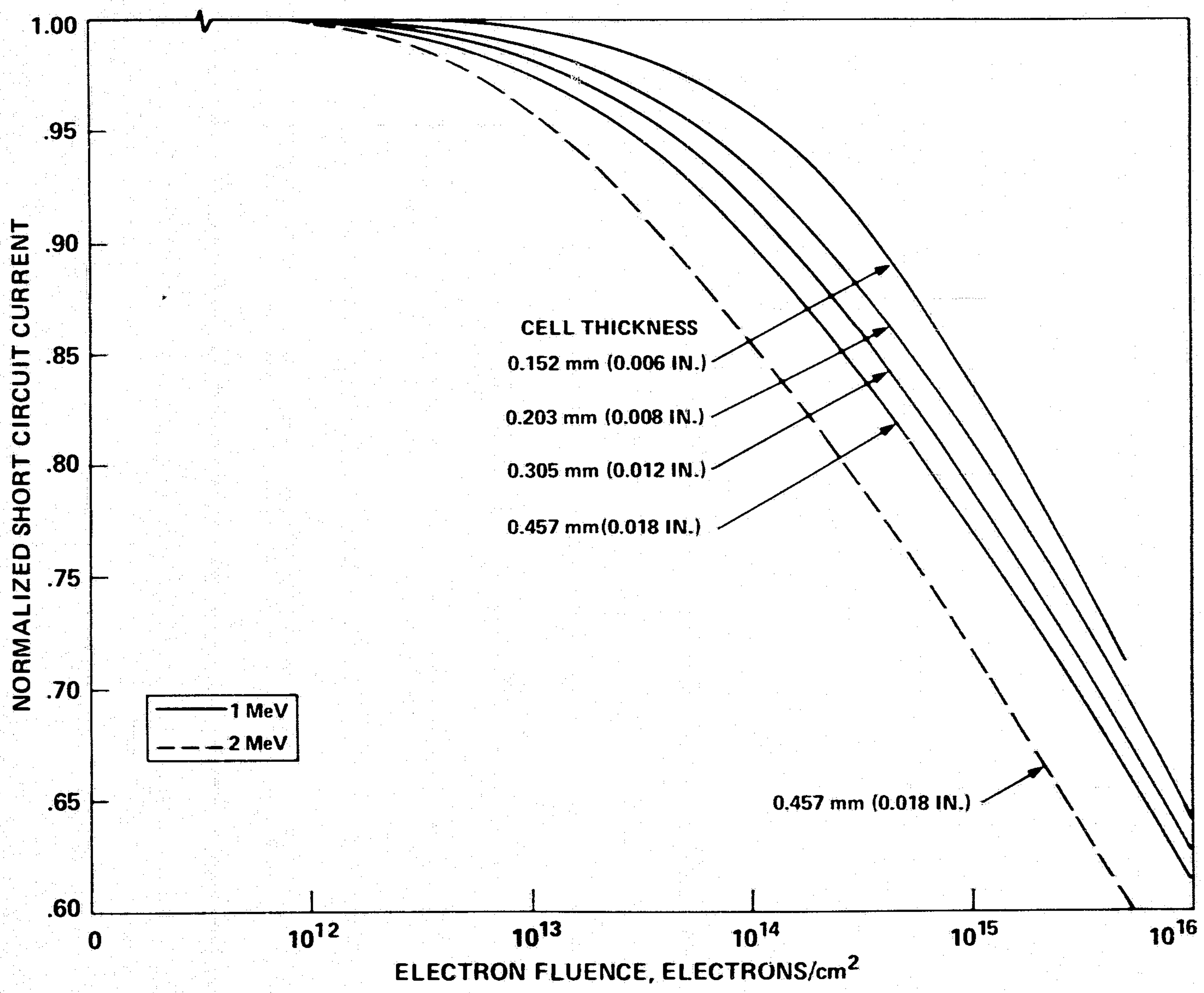

Figure 8. Normalized Short Circuit Current vs 1 MeV Electron Fluence for 2 Ohm-cm n/p Conventional Silicon Cells.[15]

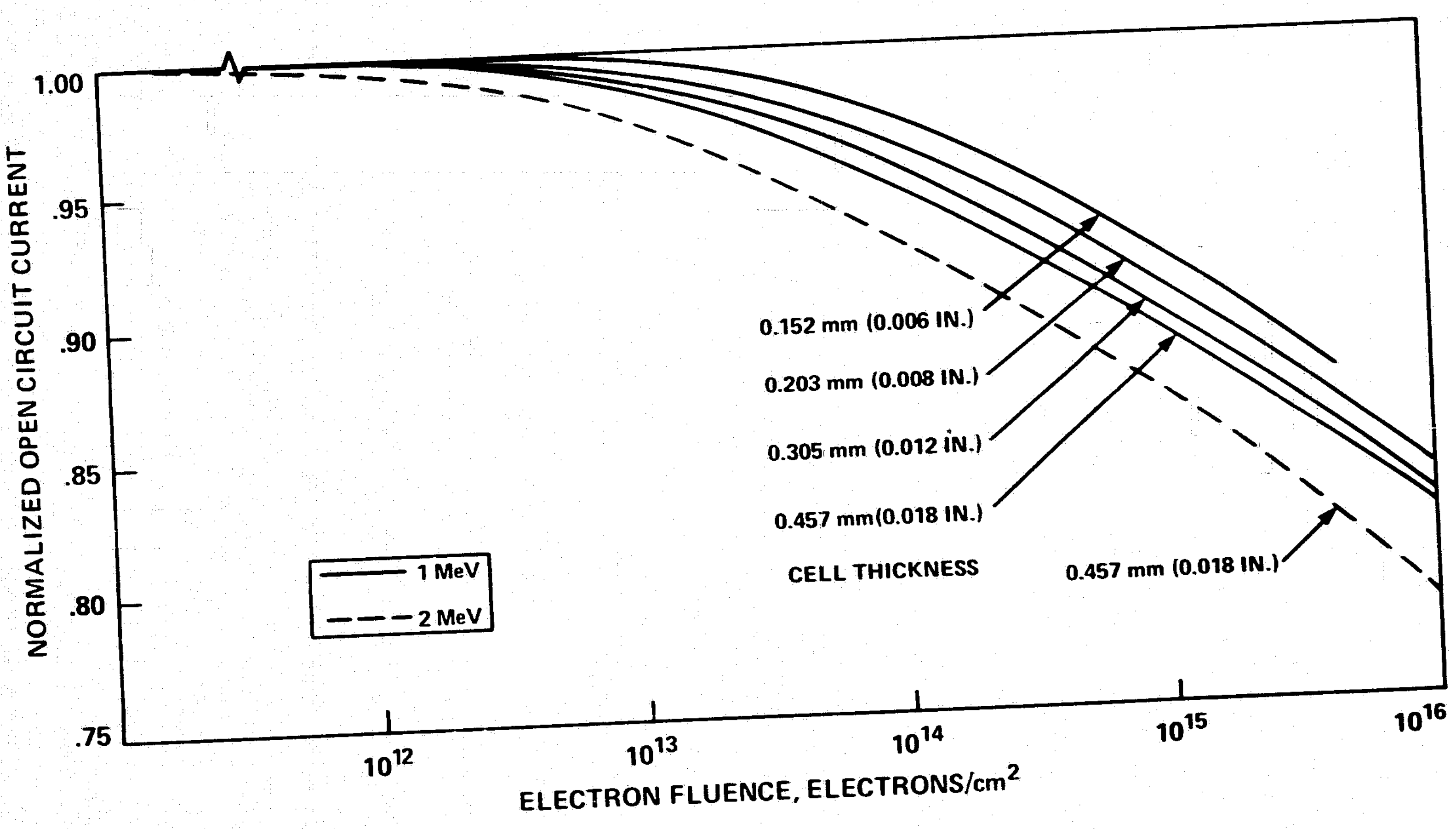

Figure 9. Normalized Open Circuit Current vs 1 MeV Electron Fluence for 2 Ohm-cm n/p Conventional Silicon Cells.[15]

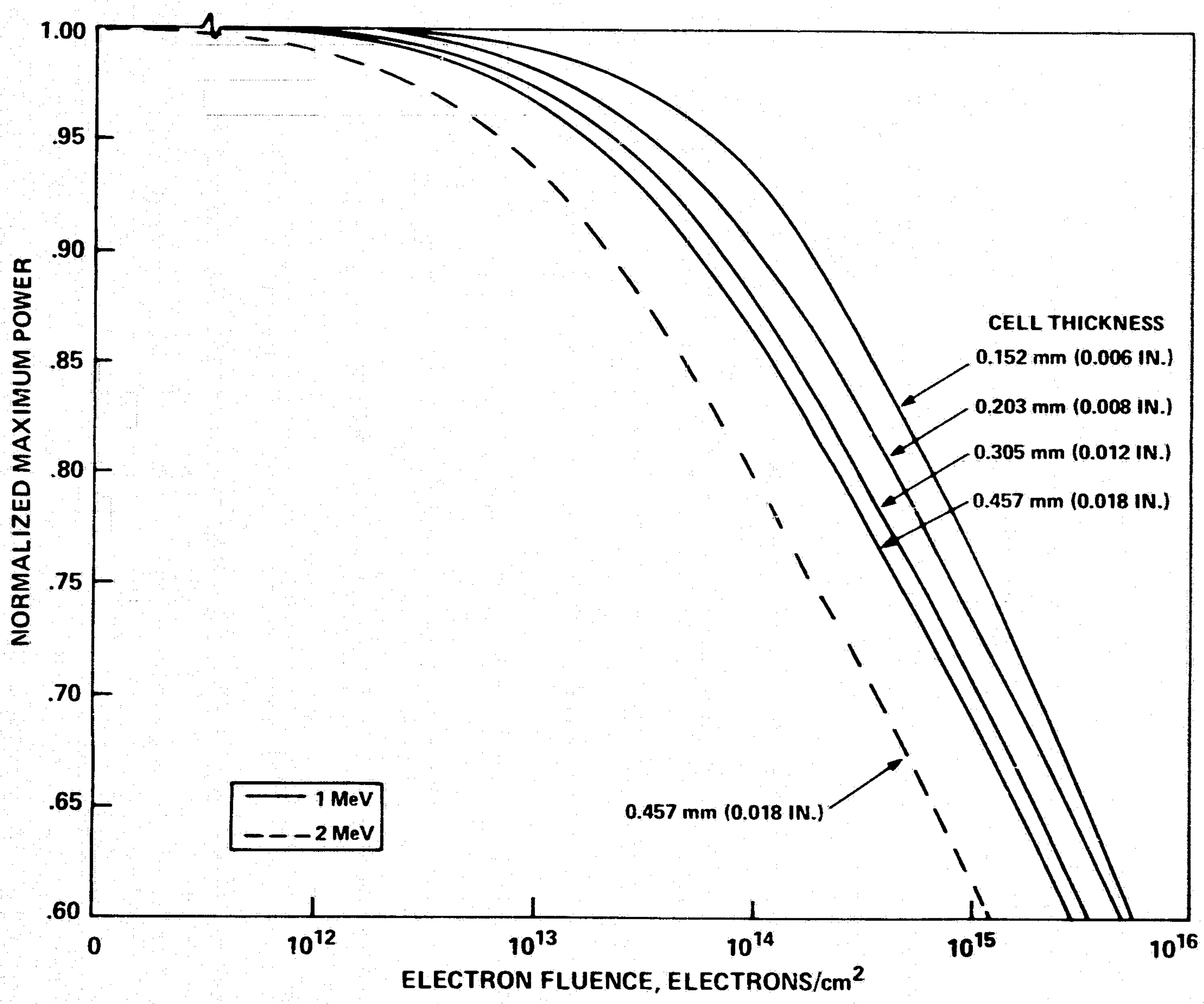

Figure 10. Normalized Maximum Power vs 1 MeV Electron Fluence for 2 Ohm-cm n/p Conventional Silicon Cells.[15]

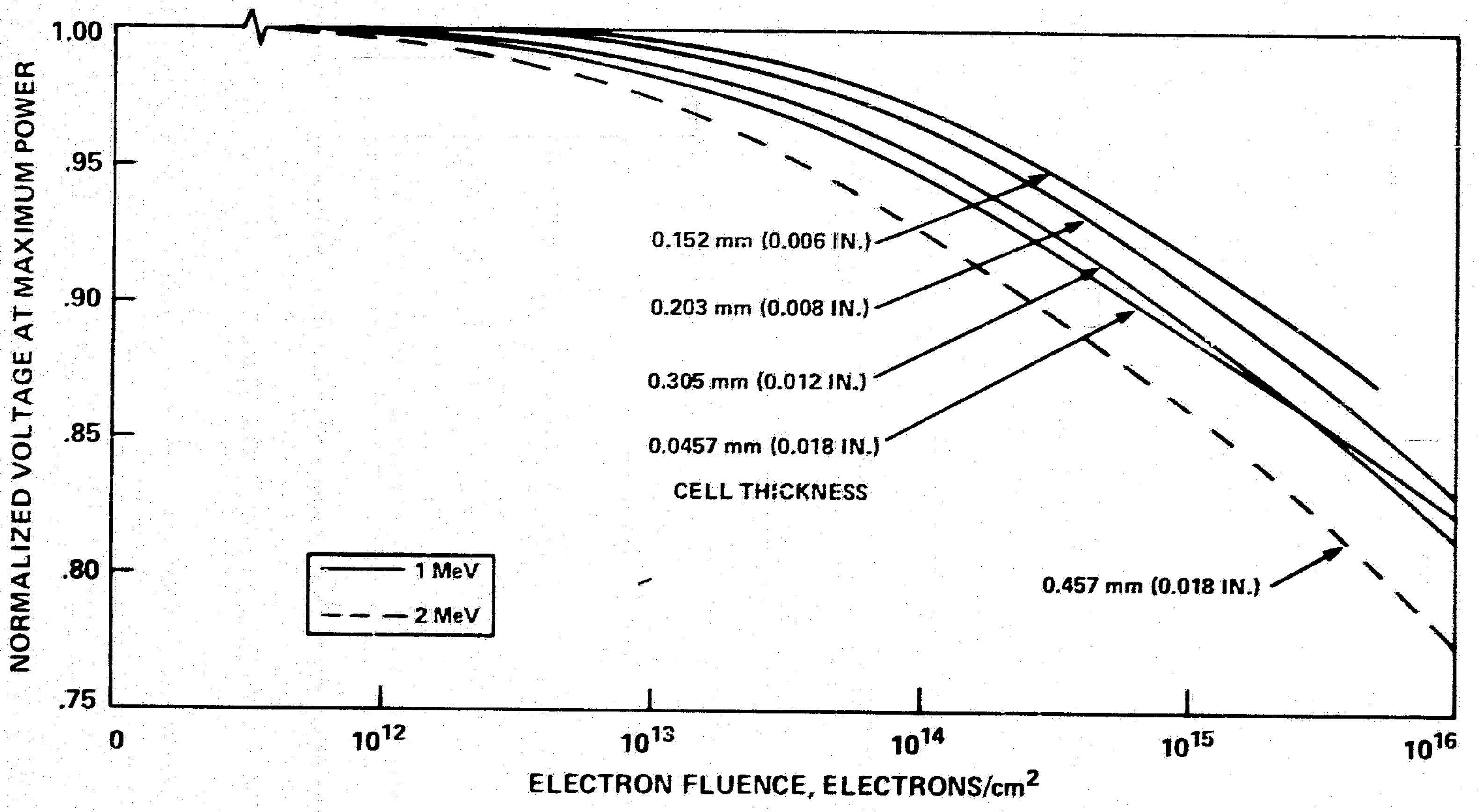

Figure 11. Normalized Voltage at Maximum Power vs 1 MeV Electron Fluence for 2 Ohm-cm n/p Conventional Silicon Cells.[15]

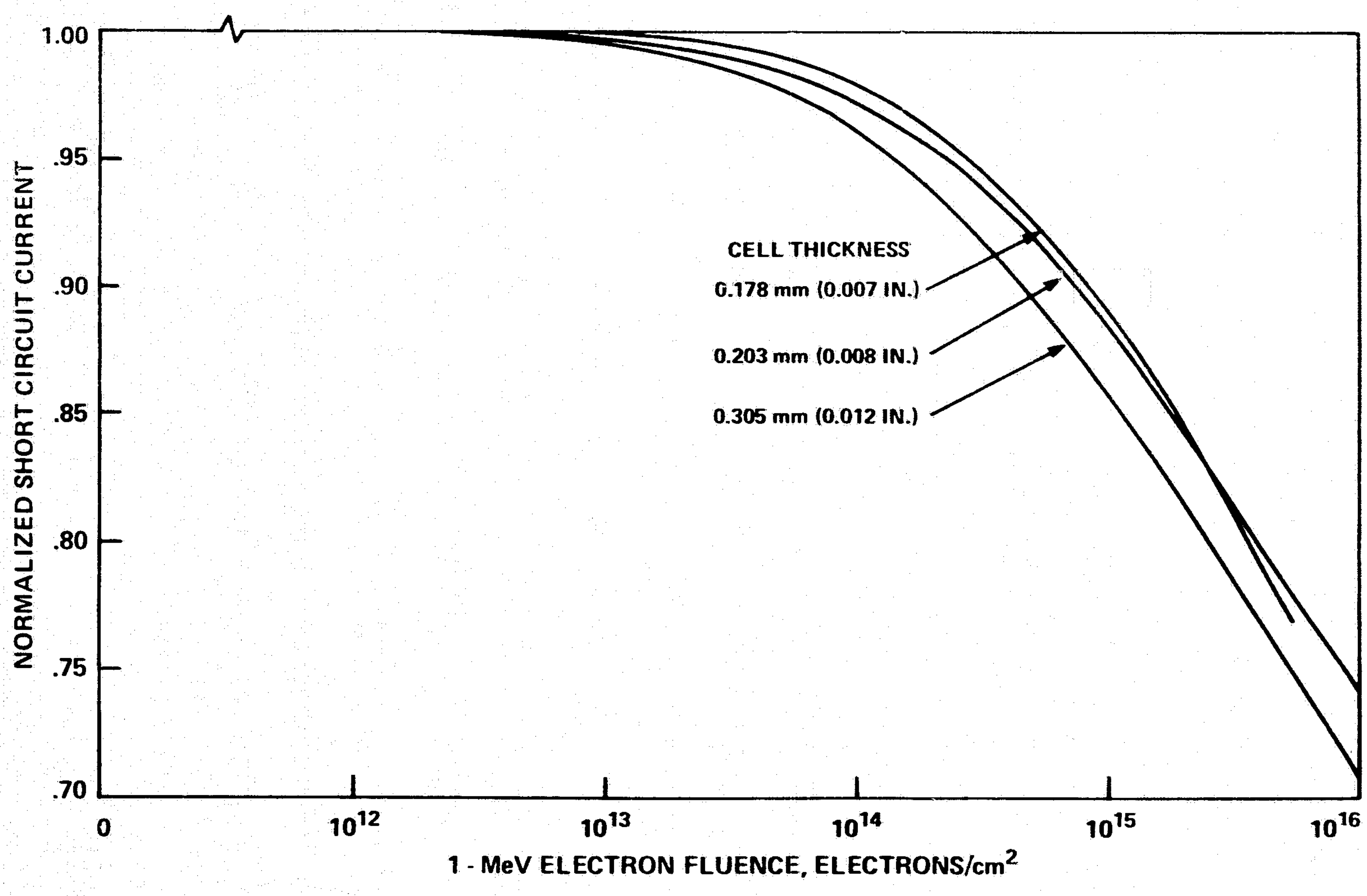

Figure 12. Normalized Short Circuit Current vs 1 MeV Electron Fluence for 10 Ohm-cm n/p Conventional Silicon Cells.[15]

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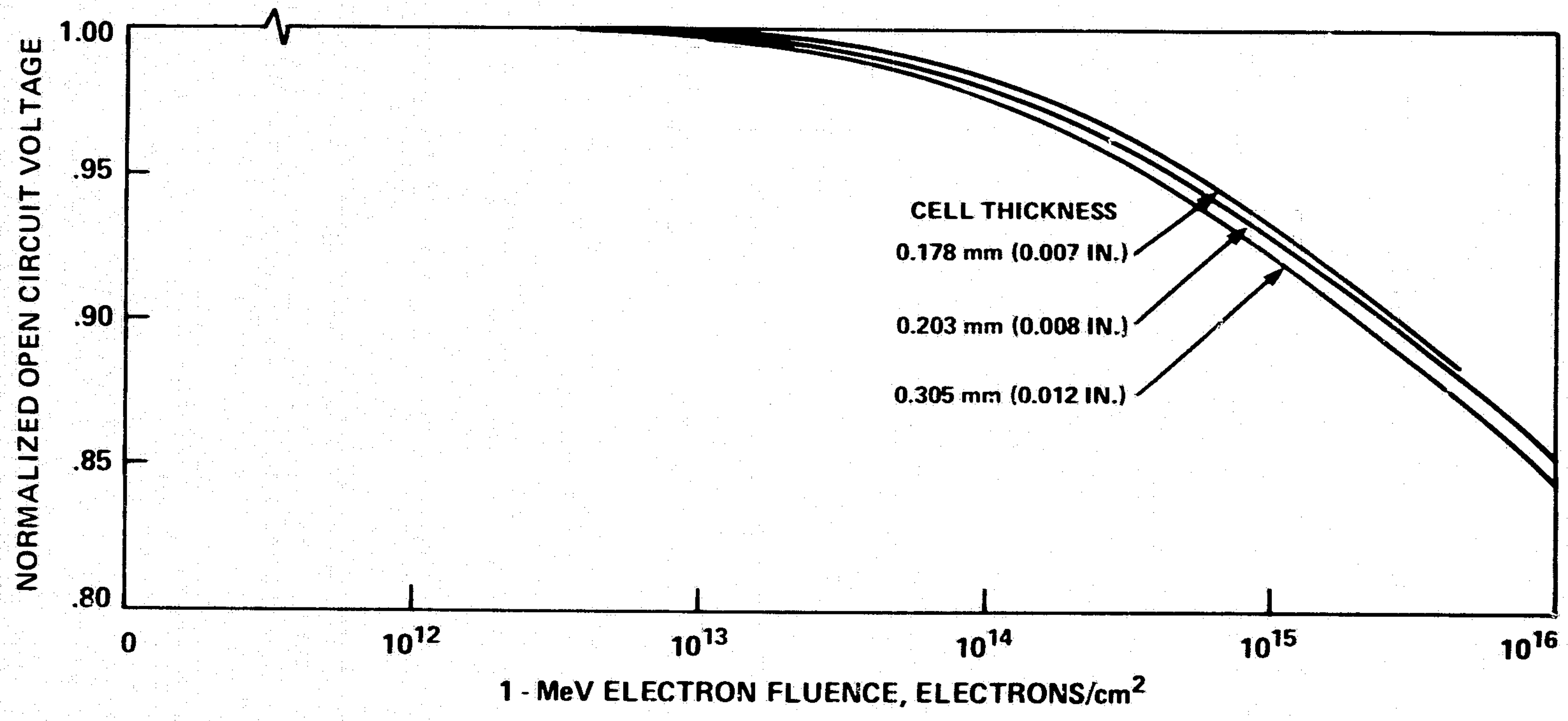

Figure 13. Normalized Open Circuit Voltage vs 1 MeV Electron Fluence for 10 Ohm-cm n/p Conventional Silicon Cells.[15]

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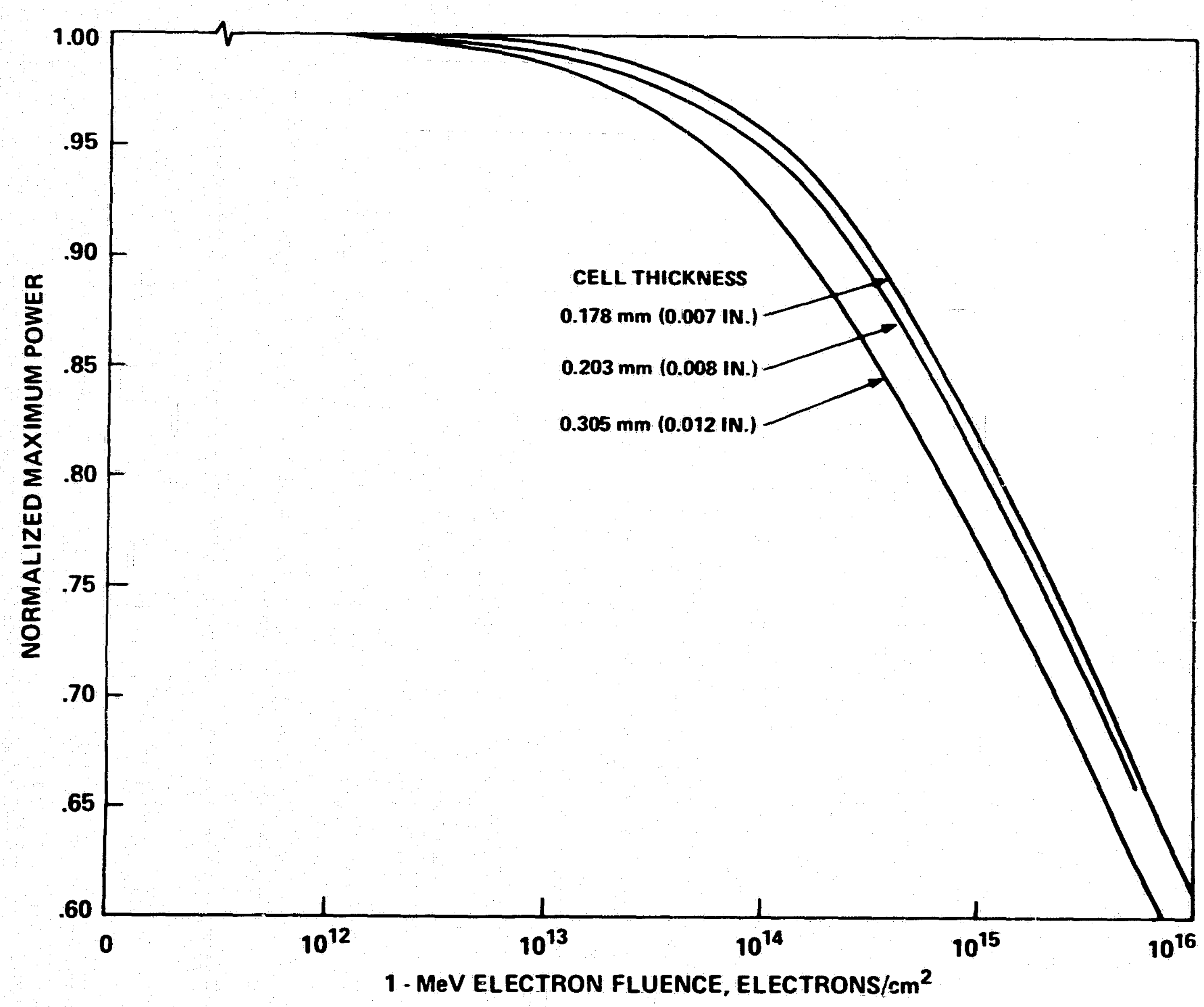

Figure 14. Normalized Maximum Power vs 1 MeV Electron Fluence for 10 Ohm-cm n/p Conventional Silicon Cells.[15]

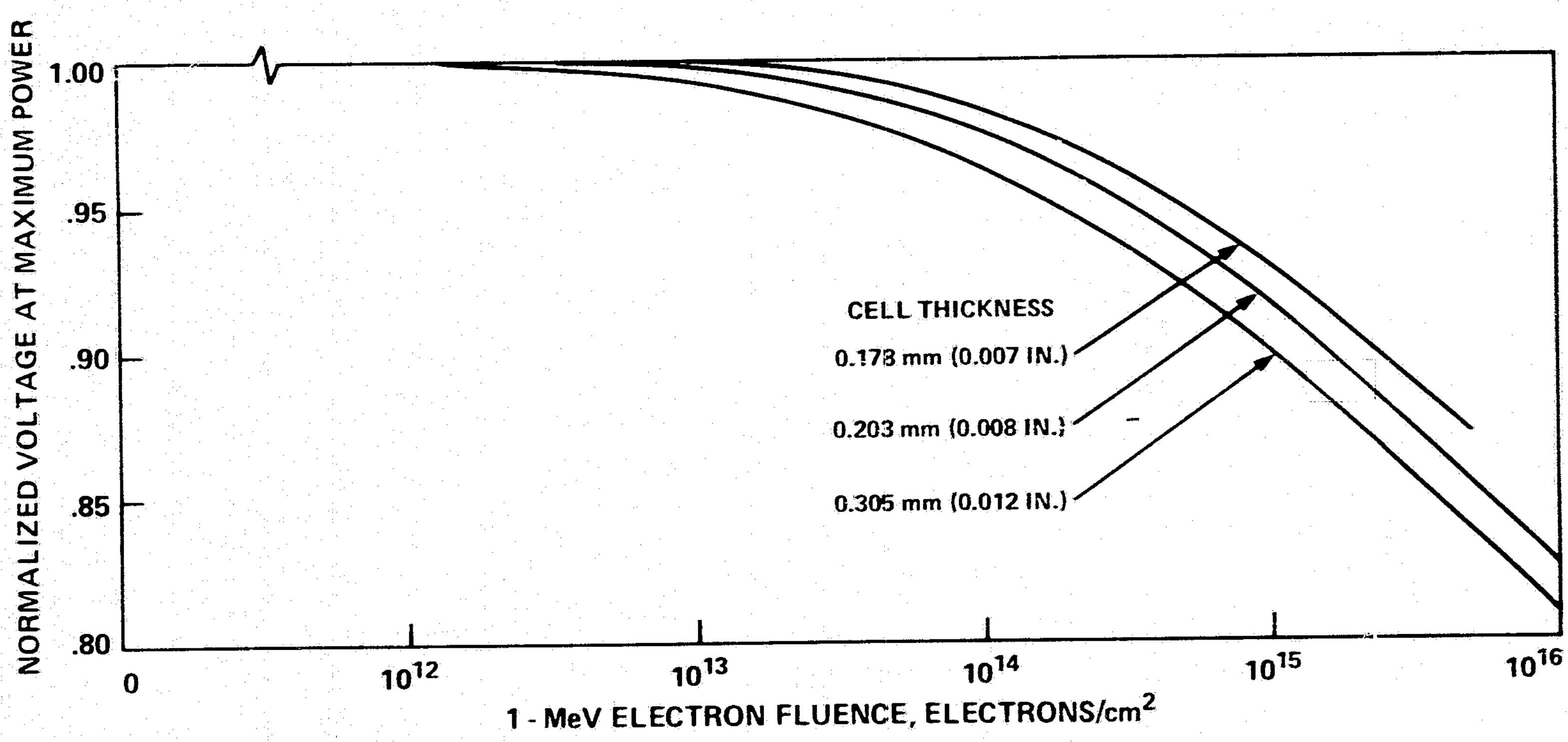

Figure 15. Normalized Voltage at Maximum Power vs 1 MeV Electron Fluence for 10 Ohm-cm n/p Conventional Silicon Cells.[15]

pression of the following form,

$$Y(T) = Y(T_O) + b(T_O)\,(T-T_O),$$

where $b(T_O)$ is the temperature coefficient at an arbitrary reference temperature T_O. In this work, the reference temperature is 30°C. The temperature coefficient for each I-V parameter is dependent on radiation damage. This dependence has been characterized in the literature[15] for 2 Ω-cm and 10 Ω-cm cells at 30°C. These data are shown in Figures 16-19. The value of the temperature coefficient for each I-V parameter of the typical (1 Ω-cm) IUE cell was determined by interpolation. The best case results for the temperature dependence of the IUE cell parameters after 3 years are:

$I_{SC} = 120.24\text{ mA} + .0954\text{ mA/°C} \cdot (T - 30°C)$
$V_{OC} = 571.52\text{ mV} - 2.10\text{ mV/°C} \cdot (T - 30°C)$
$P_{MAX} = 51.22\text{ mW} - .162\text{ mW/°C} \cdot (T - 30°C)$
$V_{MP} = 480.01\text{ mV} - 1.86\text{ mV/°C} \cdot (T - 30°C)$
$I_{MP} = P_{MAX}/V_{MP}$

The resulting worst case I-V parameters are given by:

$I_{SC} = 106.12\text{ mA} + .113\text{ mA/°C} \cdot (T - 30°C)$
$V_{OC} = 555.97\text{ mV} - 2.19\text{ mV/°C} \cdot (T - 30°)$
$P_{MAX} = 43.97\text{ mW} - .149\text{ mW/°C} \cdot (T - 30°)$
$V_{MP} = 468.74\text{ mV} - 1.88\text{ mV/°C} \cdot (T - 30°)$
$I_{MP} = P_{MAX}/V_{MP}$

These equations are valid only in the temperature region where the temperature coefficients do not vary substantially from their value at 30°C. This is the case with the temperature coefficients for I_{SC} over the range (−150°C to 60°) to which the IUE solar array is subjected. However, the temperature coefficients for P_{MAX} changes almost linearly at a rate of $-1.65\times10^{-5}\ P_{MAX}$/°C/°C. In the case of V_{OC} and V_{MP}, the temperature coefficients remain constant at temperatures above −20°C and change almost linearly at a rate of −.005 mV/°C/°C at temperatures below −20°C.[17]

Once the I–V parameters have been determined for a given cell temperature; illumination and radiation damage, the cell current I for a specified operating voltage V must be determined. There are several analytical models[17] that are generally used to approximate the shape of the solar cell I-V curve. One such model that has displayed excellent accuracy below illumination levels of two solar constants is given below.[18]

$$I = I_{SC}(1 + C_1 \{1 - \exp[V/(C_2 V_{OC})]\})$$

where $C_1 = [1 - (I_{MP}/I_{SC})] \exp[-V_{MP}/(C_2 V_{OC})]$

and $C_2 = [(V_{MP}/V_{OC}) - 1]/\ln[1 - (I_{MP}/I_{SC})]$

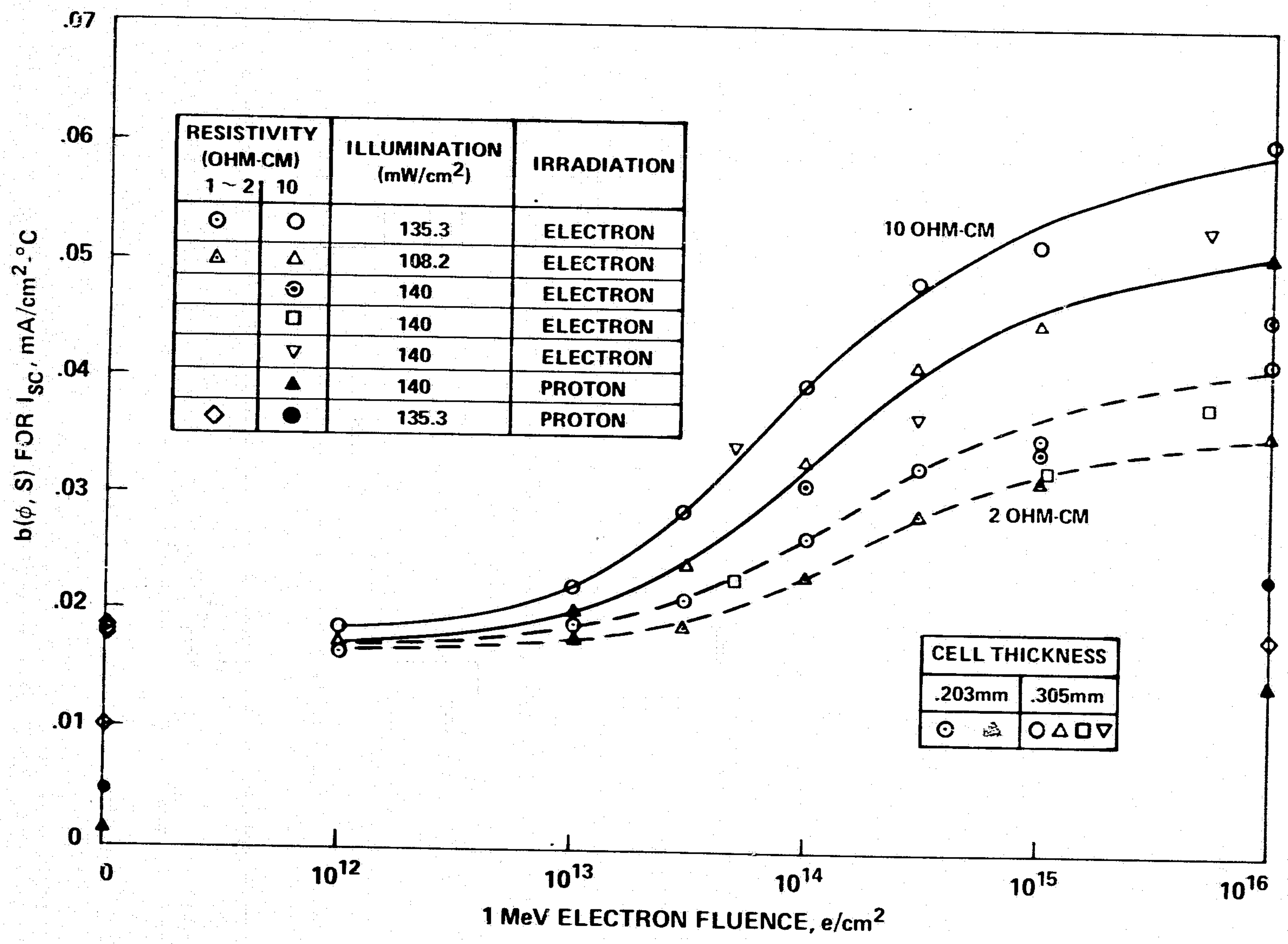

Figure 16. I_{SC} Temperature Coefficient vs 1 MeV Electron Fluence.[15]

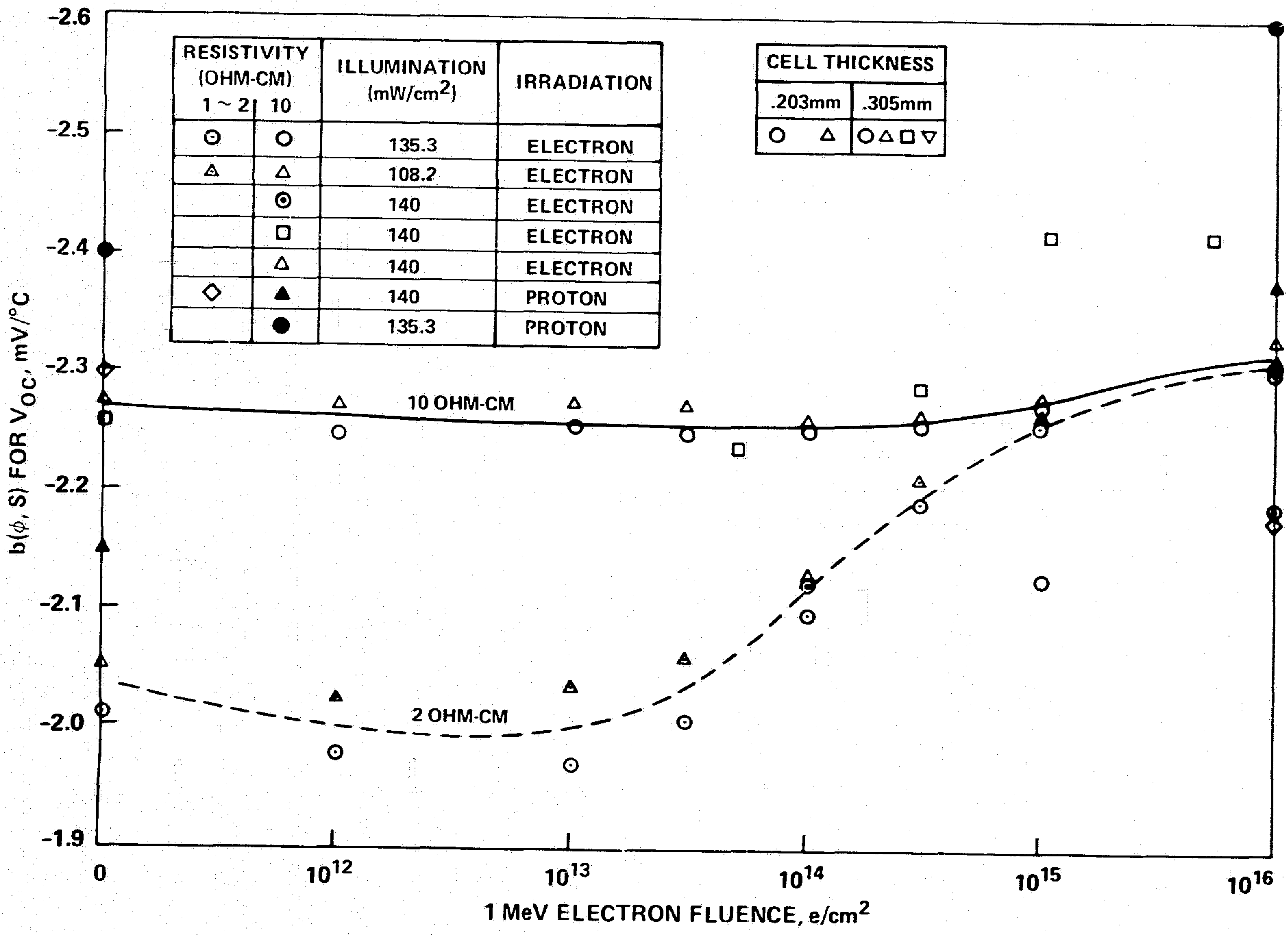

Figure 17. V_{OC} Temperature Coefficient vs 1 MeV Electron Fluence.[15]

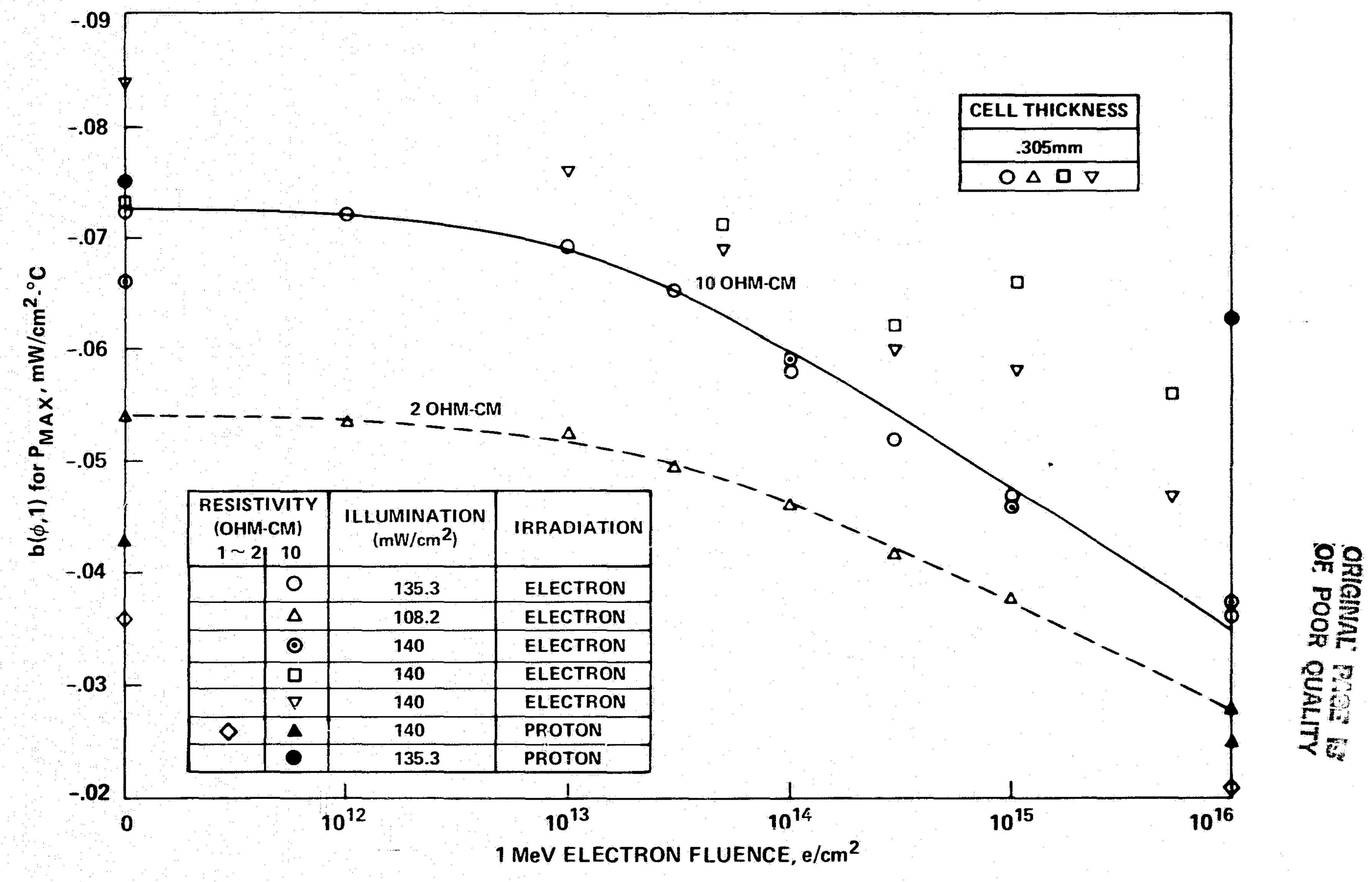

Figure 18. P_{MAX} Temperature Coefficients vs 1 MeV Electron Fluence.[15]

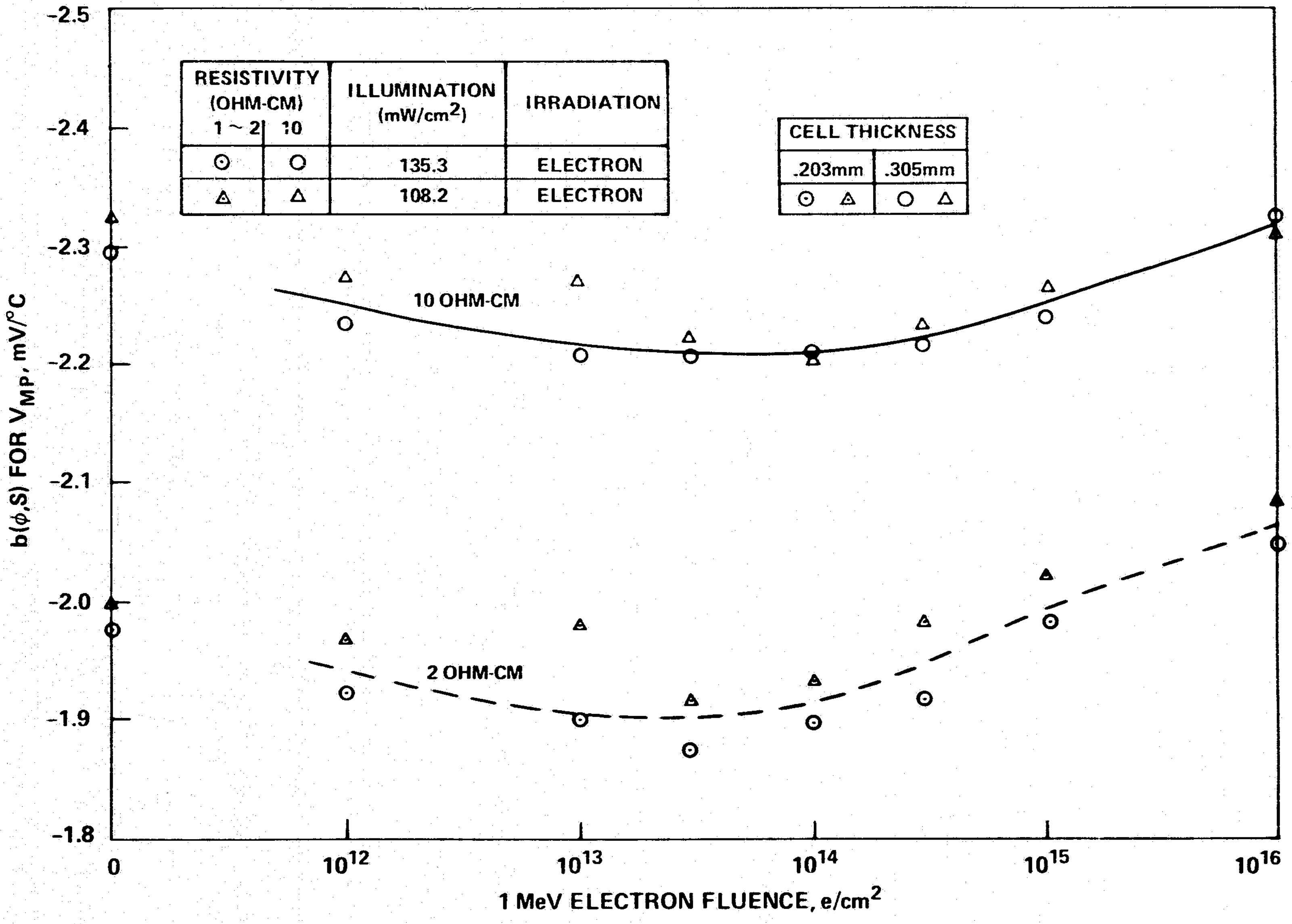

Figure 19. V_{MP} Temperature Coefficient vs 1 MeV Electron Fluence.[15]

This model has been used in this work to approximate the shape of the I-V curve for the average IUE solar cell. A computer program (Appendix B) has been used to calculate the I-V parameters of the average IUE solar cell (under 1 solar constant illumination) as a function of cell temperature and radiation damage as well as plot the I-V curve using the above model. A family of I-V curves for the best and worst cases IUE cell after three years in flight are shown in Figures 20 and 21.

ARRAY POWER OUTPUT

The prevailing variables (namely, temperature, radiation damage and illumination) upon which the average IUE solar cell I-V parameters are dependent have been quantified in the previous sections. Thus, the IUE solar array power may now be determined in terms of the average IUE solar cell operating current for a specified β angle. The procedure for performing the calculation is outlined below.

Sun position	$\beta = 0^\circ$ to 135°	
Cell Temperature	$T = 37.4 + 1.10\beta - .0185\beta^2 \pm 3.7^\circ C$ $T = -12.2 + 2.13\beta - .0156\beta^2 \pm 3.7^\circ C$ $T = -126 + 3.51\beta - .0165\beta^2 \pm 3.7^\circ C$	lower panel central panel upper panel
I-V Parameters for 1 SC Illumination	$I_{SC}(T,\phi,1) = I_{SC}(30^\circ C,\phi,1) + b_{SC}(\phi)(T - 30^\circ)$ $V_{OC}(T,\phi,1) = V_{OC}(30^\circ C,\phi,1) + b_{OC}(\phi)(T - 30^\circ)$ $P_{MAX}(T,\phi,1) = P_{MAX}(30^\circ C,\phi,1) + b_{MAX}(\phi)(T - 30^\circ)$ $V_{MP}(T,\phi,1) = V_{MP}(30^\circ C,\phi,1) + b_{MP}(\phi)(T - 30^\circ C)$ $I_{MP}(T,\phi,1) = P_{MAX}(T,\phi,1)/V_{MP}(T,\phi,1)$	
Cell operating voltage	$V_{OP} = 389$ mV $V_{OP} = 423$ mV $V_{OP} = 389$ mV	lower panel central panel upper panel
Cell operating current for 1 SC Illumination	$C_2 = [(V_{MP}/V_{OC}) - 1]/\ln[1 - (I_{MP}/I_{SC})]$ $C_1 = [1 - (I_{MP}/I_{SC})] \cdot \exp[-V_{MP}/(C_2 \cdot V_{OC})]$ $I_{OP}(T,\phi,1) = I_{SC} \cdot \left\{1 + C_1(1 - \exp[V_{OP}/(C_2 \cdot V_{OC})]\right\}$	
panel view angle	$\theta = \beta - 22.5^\circ$ $\theta = \beta - 67.5^\circ$ $\theta = \beta - 112.5^\circ$	lower panel central panel upper panel
Illumination Factor	$S = \cos\theta$	

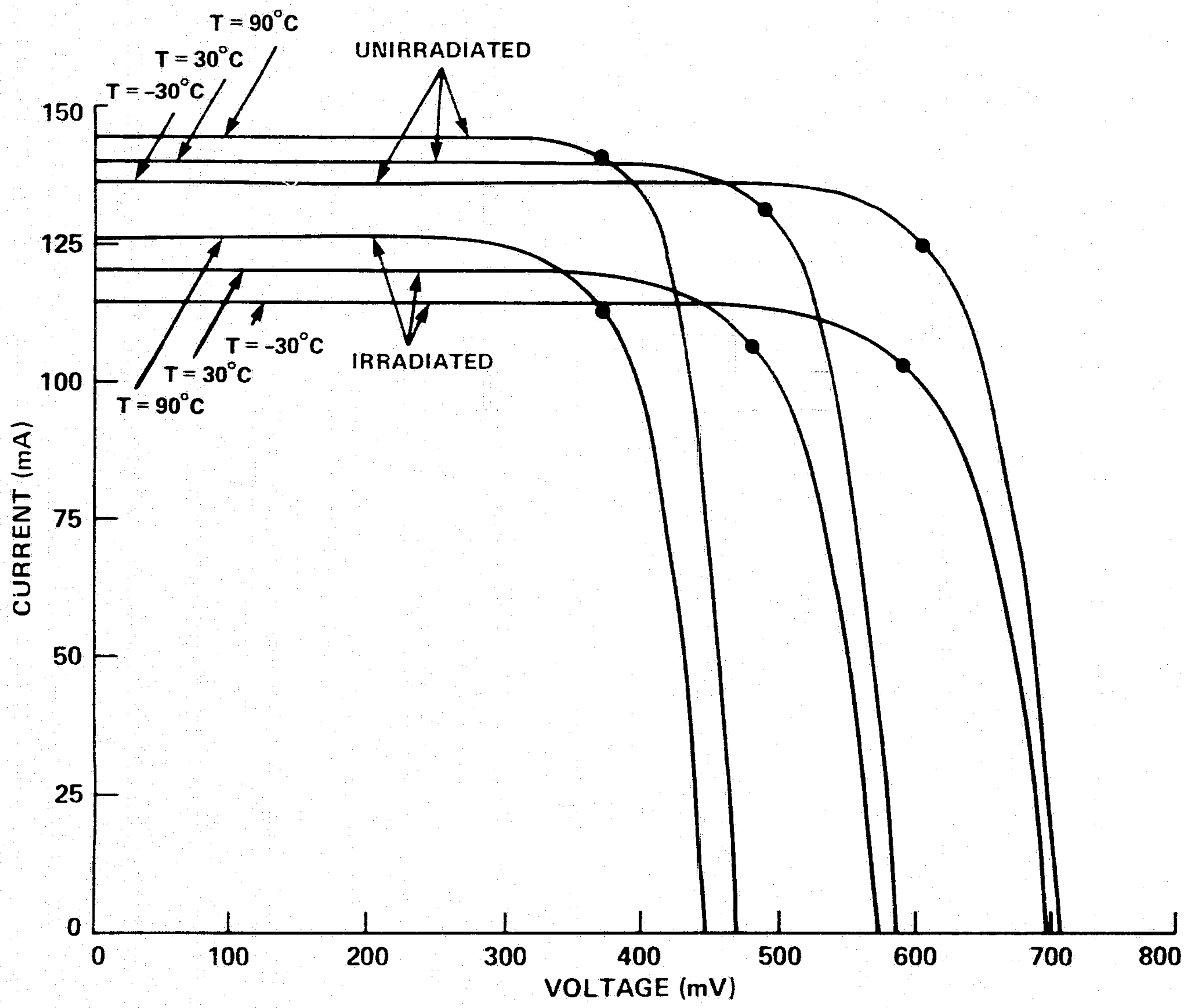

Figure 20. I-V curves for the typical IUE cell: Best Case.

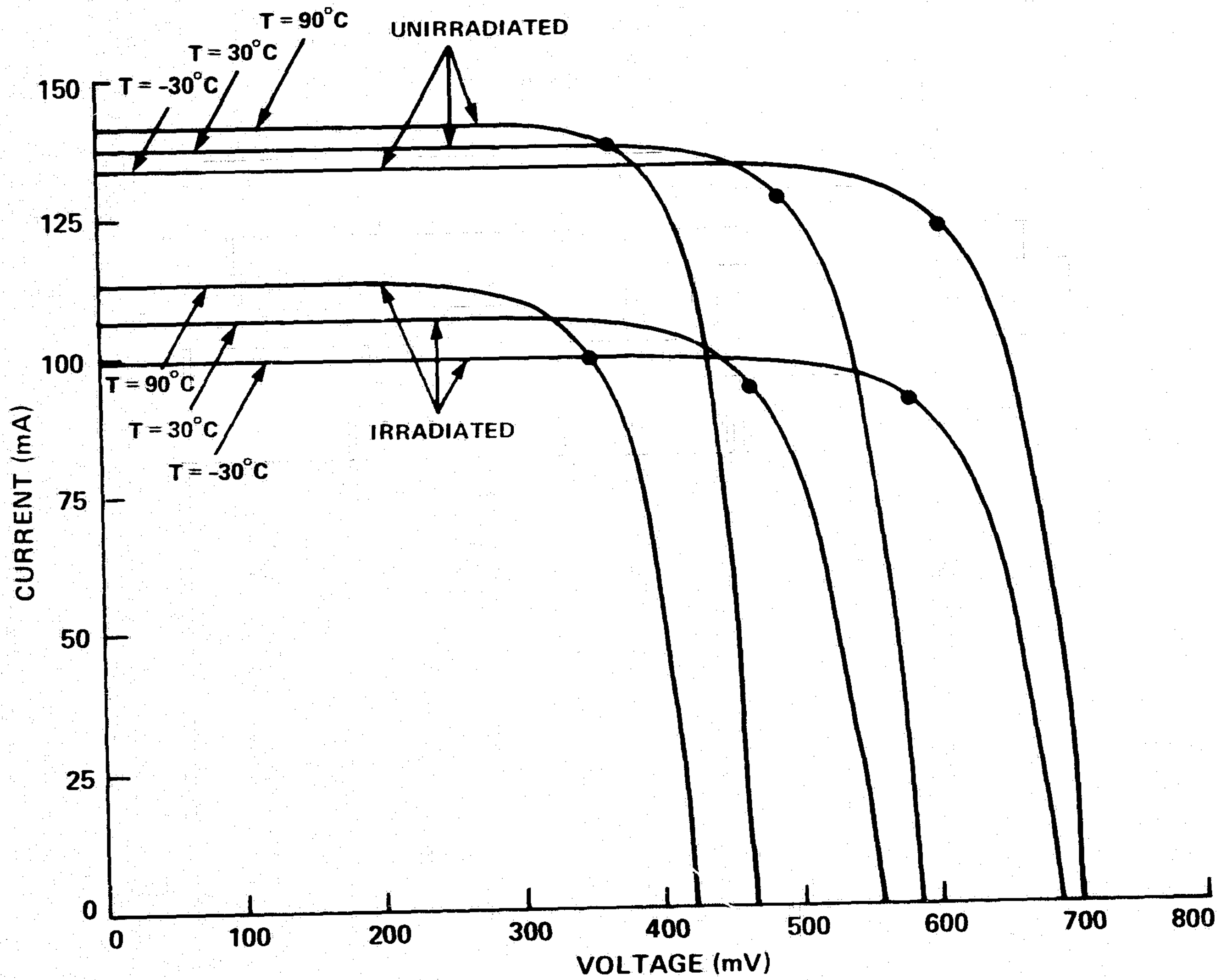

Figure 21. I-V curves for the typical IUE cell: Worst Case.

Short Circuit Current	$I_{SC}(T,\phi,S) = S \cdot I_{SC}(T,\phi,1)$		
Short circuit current net loss factor	f_{SC}	(See Table 9)	
corrected short circuit current	$I_{SC}(T,\phi,S) \rightarrow f_{SC} \cdot I_{SC}(T,\phi,S)$		
cell operating current	$I_{OP}(T,\phi,S) = I_{OP}(T,\phi,1) - [I_{SC}(T,\phi,1) - I_{SC}(T,\phi,S)]$		
operating current net loss factor	f_{OP}	(See Table 10)	
corrected operating current	$I_{OP}(T,\phi,S) \rightarrow f_{OP} \cdot I_{OP}(T,\phi,S)$		
panel power output	$P_l = 28 \text{ volts} \cdot 24 \cdot I_{OP}(T_l,\phi,S_l)$ $P_c = 28 \text{ volts} \cdot 20 \cdot I_{OP}(T_c,\phi,S_c)$ $P_u = 28 \text{ volts} \cdot 24 \cdot I_{OP}(T_u,\phi,S_u)$		lower panel central panel upper panel
Net Available Array Power	$P = 2 \cdot P_l + 2 \cdot P_c + 2 \cdot P_u$		

The calculations outlined above were performed to obtain the IUE solar array power after three years. The best and worst case power are plotted in Figure 22 as a function of beta angle along with flight data for the available array power [19] after three years. The same is plotted in Figure 23 for the beginning of life power.[20] In both examples the flight data are between the best and worst case curves, as expected. In order that these calculations may yield the exact array power, a normalization parameter K is defined such that:

Array Power = K • (Best Case Power) + (1-K) • (Worst Case Power)

where $O \leqslant K \leqslant 1$.

Also observed in Figure 22, the array power at the lower beta angles is closer to the worst case calculation; where at the higher beta angles the array power is closer to the best case calculation. Thus, the normalization parameter K changes with the beta angle. This may be attributed to a difference in cell characteristics and engineering loss factors from the lower to upper panel and/or an angular dependence of the space radiation incident upon IUE.

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Table 9
Correction Factors for I_{SC}

fsc	Best Case	Worst Case
Solar Intensity & Orientation Error	1.035	.964
Ultraviolent & Micrometeor Degradation	1.0	.99
Net	1.035	.954

Table 10
Correction Factors for I_{OP}

fop	Best Case	Worst Case
Diode and Harness Losses	.958	.958
Cell Mismatching	1.0	.98
Random Failure	1.0	.98
Design Margin	1.0	.98
Net	.958	.902

The normalization parameters for flight data acquired after three years were statistically fitted to a second-order function in beta using a least-squares routine.[10] The result is displayed in Figure 24. This normalization parameter may be applied to the best and worst case power calculation for three years in flight. The normalized power is plotted in Figure 25 along with the corresponding flight data. The same is shown in Figure 26 for the beginning of life. As there is excellent agreement between the normalized calculation and flight data acquired at different times, the same calculations are performed to predict the IUE solar array power available in the future.

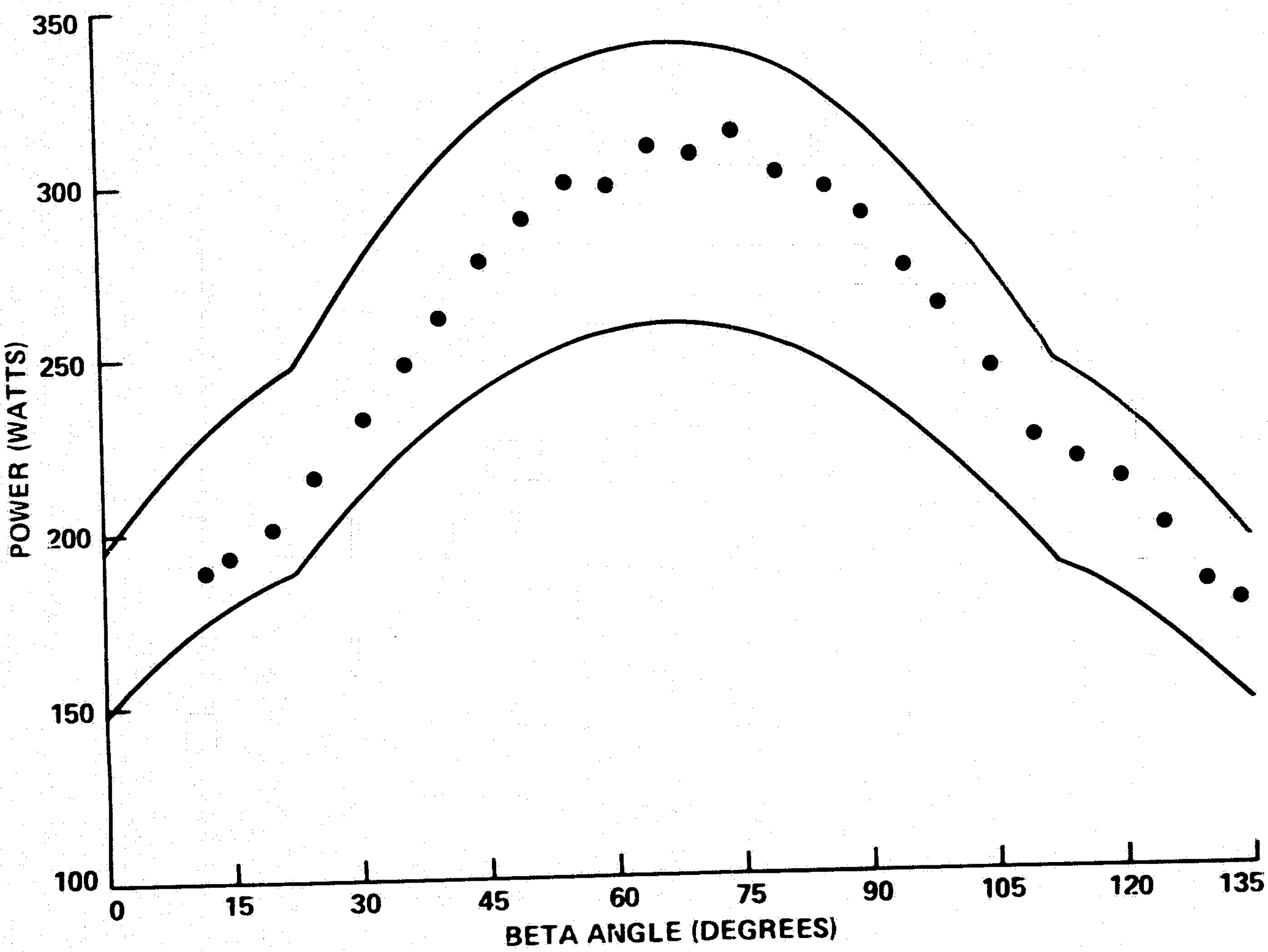

Figure 22. Flight Power Data, Best Case Power Calculation and Worst Case Power Calculation After 3 years.

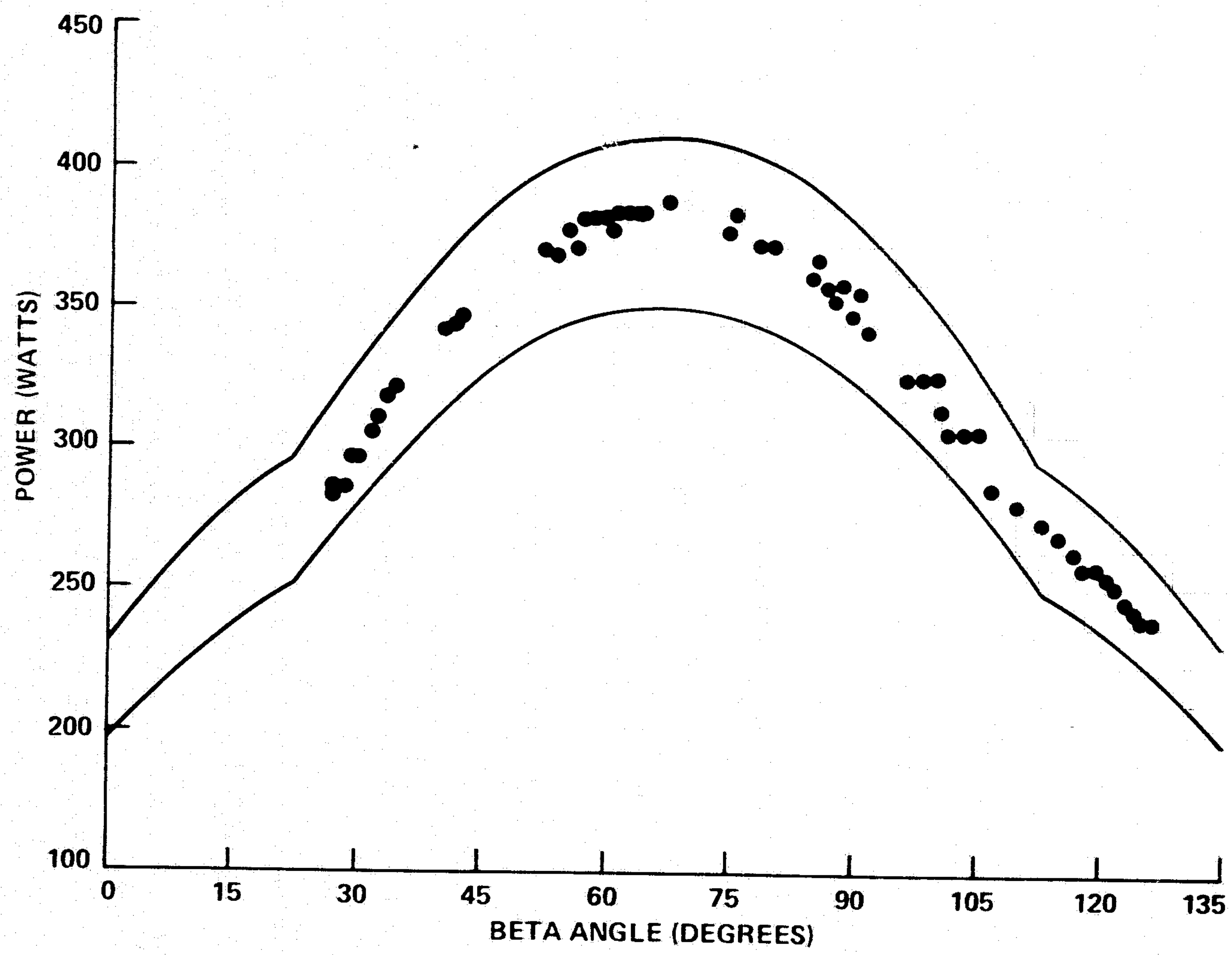

Figure 23. Flight Power Data, Best Case Power Calculation and Worst Case Power Calculation at Beginning of Life.

	COEFFICIENT	99 % CONFIDENCE INTERVAL LOWER LIMIT	UPPER LIMIT
'CONSTANT'	.06661	-.05007	.18329
X^1	.01202	.00834	.01569
X^2	-.00007	-.00009	-.00004

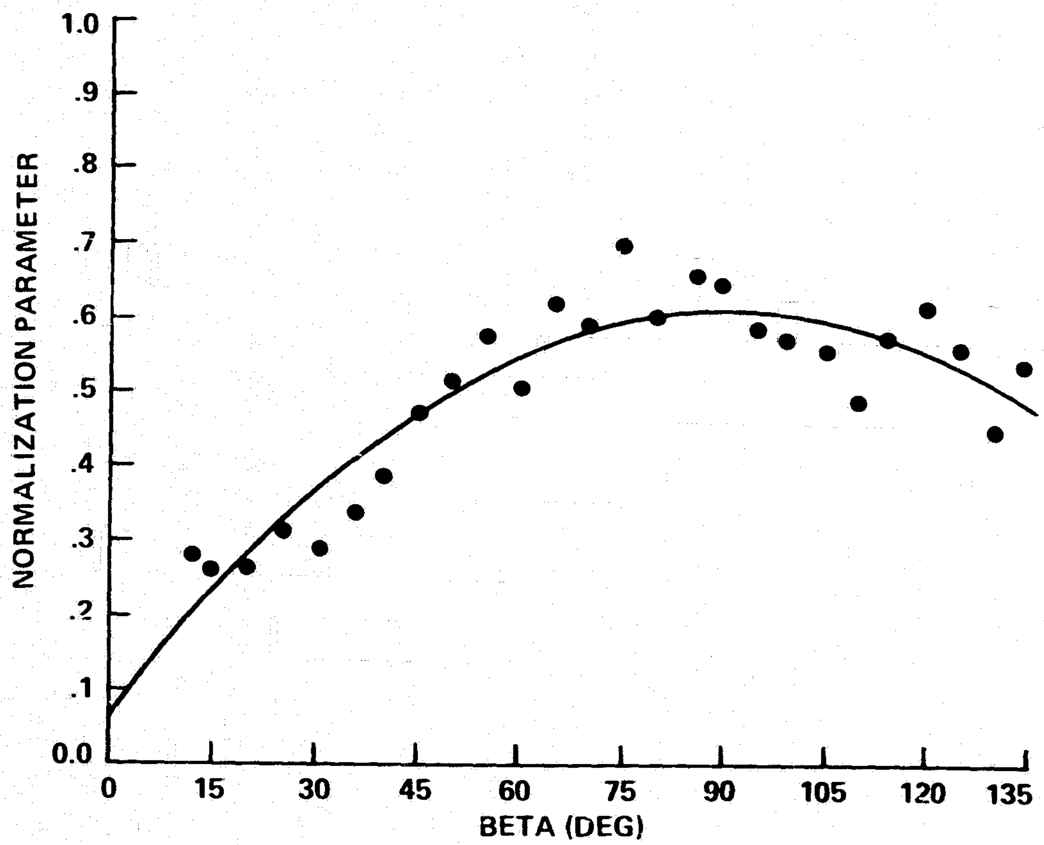

Figure 24. Dependence of Normalization Parameter on Beta Angle.

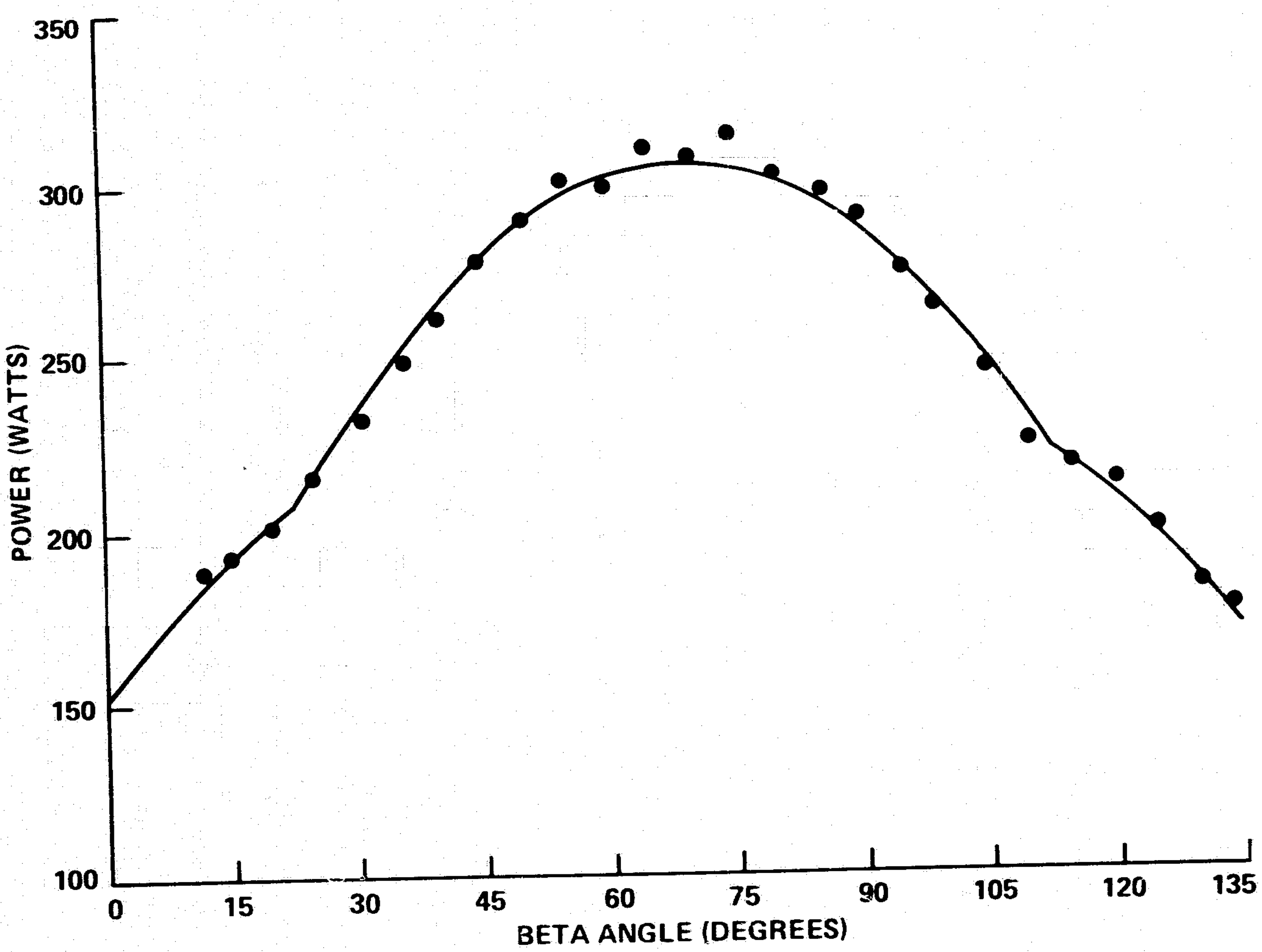

Figure 25. Flight Power Data and Normalized Power Calculation After 3 years.

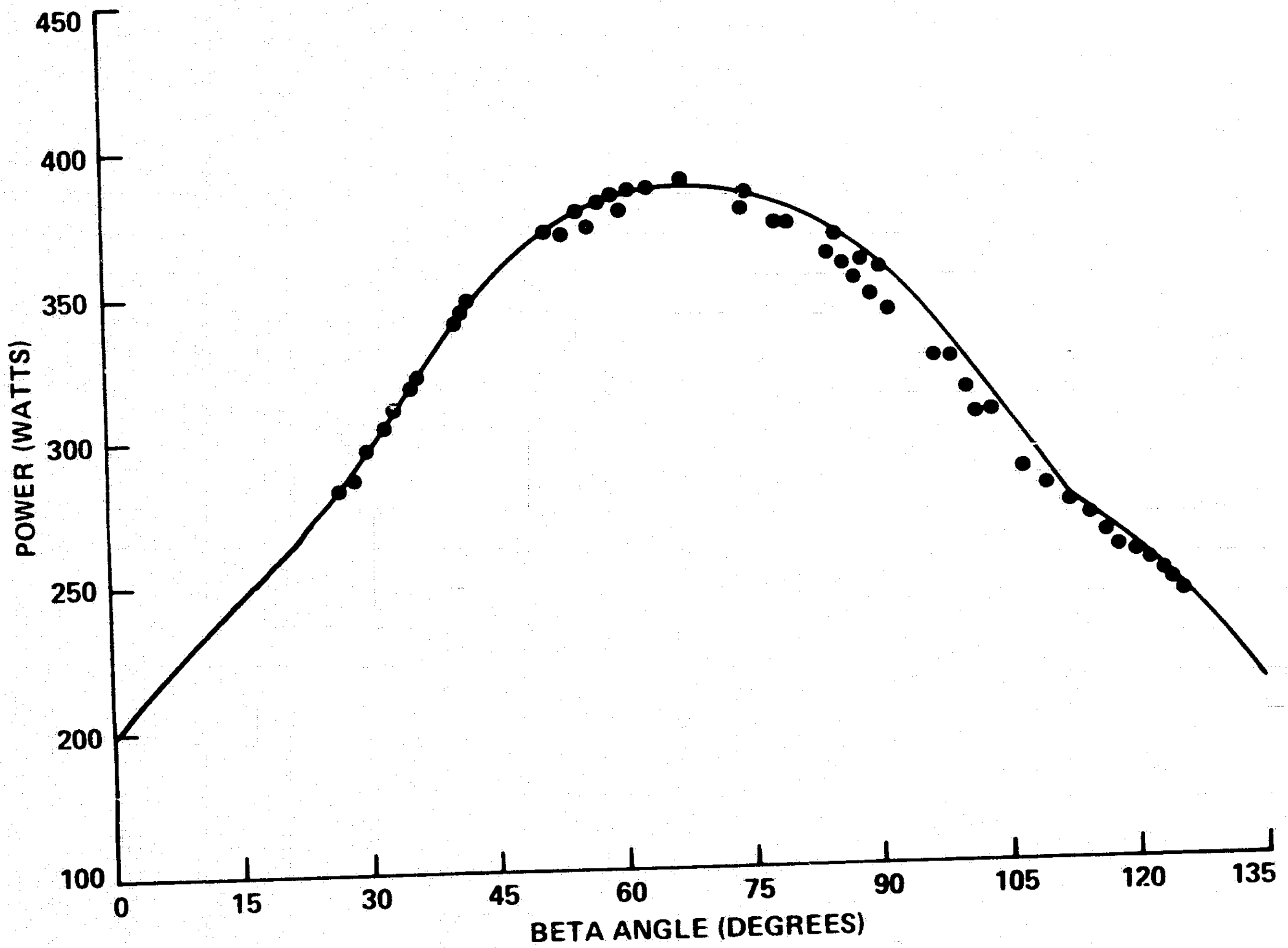

Figure 26. Flight Power Data and Normalized Power Calculation for Beginning of Life.

However, to use the normalized power calculation presented above to predict the array output, the irradiation dosage and solar cell characteristics must be known as a function of time. The increase in equivalent fluence with time is assumed to be constant at the previously calculated best and worst case values per three years. The best and worst case I-V parameters for the average IUE cell are determined for an arbitrary point in time as they were determined for three years. A computer program (Appendix C) was used to perform the normalized power calculation for each year from beginning of life to ten years. The results are plotted in Figure 27 and also given in digital form (Appendix D).

CONCLUSION

The minimum power which must be provided to IUE to maintain mission essential operations is 175 watts continuously during day light.[21] The design requirement was 186 watts.[1] As the power generating capacity of the solar array degrades with time, the beta angle region where more than 175 watts can be supplied grows smaller. Therefore, the number of stars to which IUE can be pointed are fewer. This is the critical criterion by which the future utility of IUE will be judged. The upper and lower cut off beta angles, outside which less than 175 watts will be supplied to IUE, are plotted in Figure 28. This defines the restricted region for beta as a function of time. It is shown that the IUE solar array can continue to produce more power than is required at most observatory positions for at least five more years.

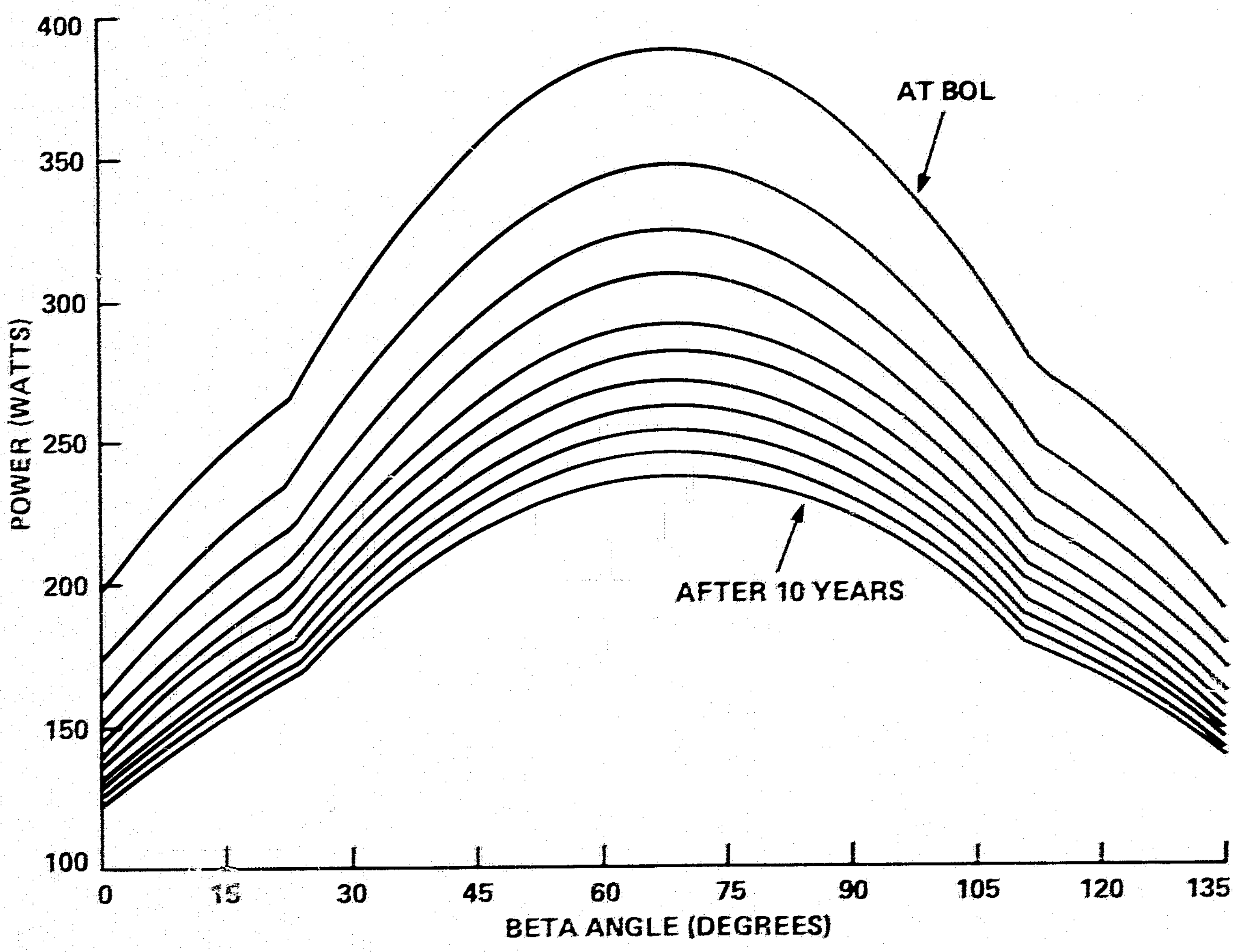

Figure 27. Available IUE Solar Array Power After Each Year From BOL to 10 years.

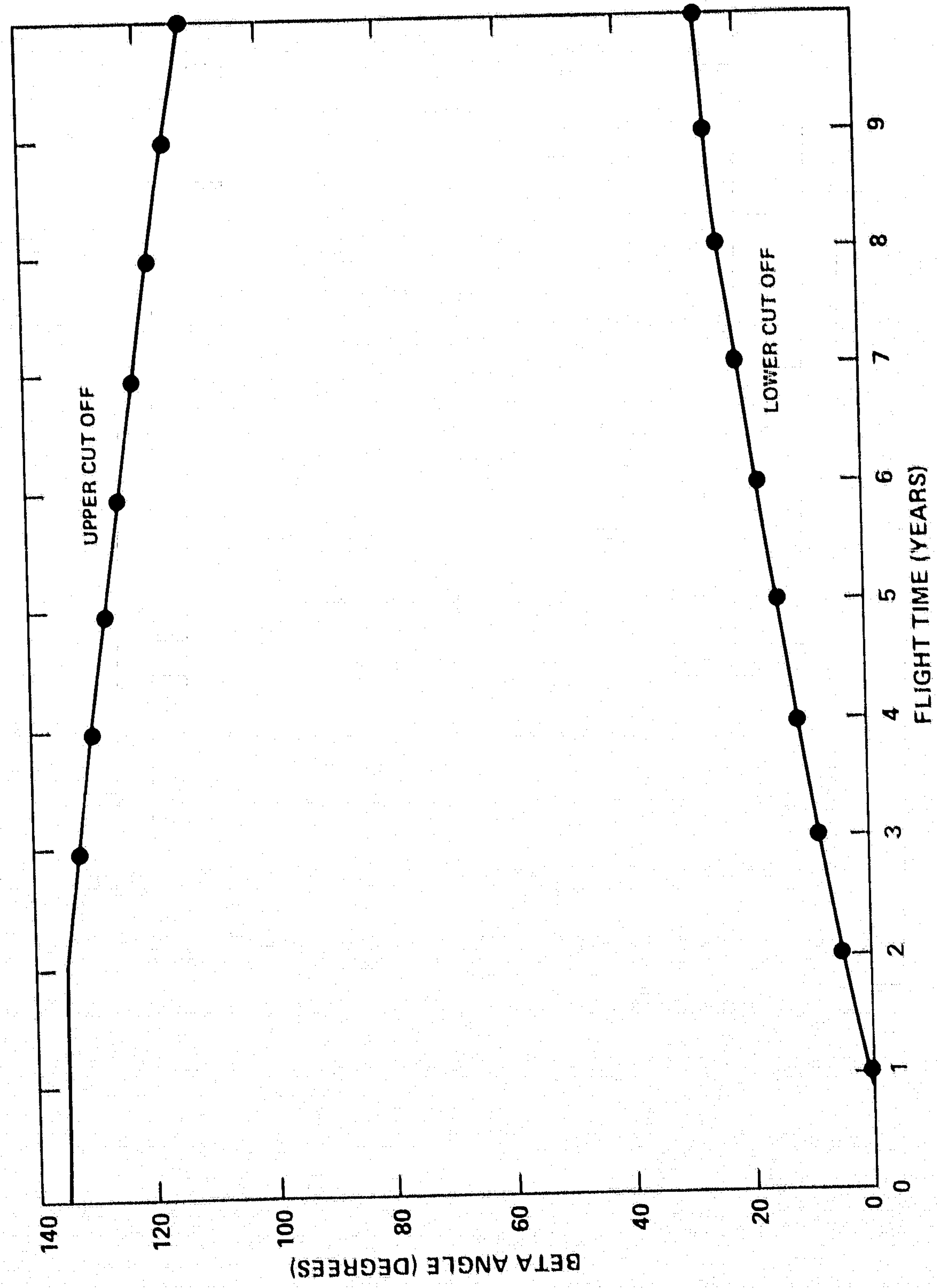

Figure 28. Restricted Beta Region versus Time.

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Appendix A – EQUFLU

```
5    REM ****************************** EQU FLU ****************************************
10   REM THIS PROGRAM CALCULATES THE EQUIVALENT 1MEV ELECTRONS AT NORMAL INCIDENCE
15   REM UPON THE SURFACE OF A SILICON SOLAR CELL DUE TO AN OMNIDIRECTIONAL
20   REM ELECTRON AND PROTON RADIATION ENVIRONMENT.
25   DIM E1(100),R1(100),E2(100),R2(100),T(100,11),D1(200),D2(200),D3(200)
30   GOSUB Elecrad
35   GOSUB Protrad
40   GOSUB Shield
45   GOSUB Ede
50   GOSUB Isepde
55   GOSUB Vocpde
60   GOSUB Flucal
65   STOP
70   Elecrad: ! *************************************************************************
75   REM THIS SUBROUTINE COLLECTS THE ELECTRON SPACE RADIATION DATA FROM THE
80   REM OPERATOR.
85   PRINT (LIN(2),"OMNIDIRECTIONAL ELECTION FLUENCE (ELECTRONS/CM^2)"
90   PRINT "                                    VERSUS"
95   PRINT "                              ELECTRON ENERGY (>MEV)"
100  PRINT (LIN(1), "TOTAL NUMBER OF OBSERVATIONS =",
105  INPUT N1
110  PRINT N1, LIN(1)
115  PRINT "THE OBSERVATION CORRESPONDING TO THE LOWEST ELECTRON ENERGY MUST BE"
120  PRINT "ENTERED FIRST. THEN ENTER THE REMAINING OBSERVATIONS IN ORDER OF"
125  PRINT "INCREASING ELECTRON ENERGY."
130  FOR I=1 TO N1
135  PRINT LIN(1),"OBSERVATION#",I
140  PRINT "ELECTRON ENERGY (>MEV) =",
145  INPUT E1(I)
150  PRINT E1(I)
155  PRINT "ELECTRON FLUENCE (ELECTRONS/CM^2) =",
160  INPUT R1(I)
165  PRINT R1(I)
170  NEXT I
175  PRINT LIN(1),"CHECK THE ABOVE DATA AGAIN."
180  PRINT "IF CORRECTIONS ARE REQUIRED ENTER 0"
185  PRINT "IF DATA IS CORRECT ENTER ANY OTHER NUMBER"
190  INPUT X
195  IF X=0 THEN 85
200  PRINTER IS 0
205  PRINT LIN(1),"ELECTRON","FLUENCE","FLUENCE","DIFFERENTIAL"
210  PRINT "ENERGY","ELECTRONS/CM^2)","(ELECTRONS/CM^2)","FLUENCE"
215  PRINT "(MEV)","> E-(dE/2)","> E+(dE/2)","(ELECTRONS/CM^2)"
220  FOR I=1 TO N1-1
225  E1(I)=(E1(I)+E1(I+1))/2
230  PRINT E1(I),R1(I),R1(I+1),R1(I)-R1(I+1)
235  NEXT I
240  N1=N1-1
245  PRINTER IS 16
```

```
250   RETURN
255   Protrad: ! ****************************************************************************
260   REM THIS SUBROUTINE COLLECTS THE PROTON SPACE RADIATION DATA FROM THE
265   REM OPERATOR.
270   PRINT LIN(2),"OMNIDIRECTIONAL PROTON FLUENCE (PROTONS/CM^2)"
275   PRINT "                                   VERSUS"
280   PRINT "                                   PROTON ENERGY (>MEV)"
285   PRINT LIN(1),"TOTAL NUMBER OF OBSERVATIONS =",
290   INPUT N2
295   PRINT N2,LIN(1)
300   PRINT "THE OBSERVATION CORRESPONDING TO THE LOWEST PROTON ENERGY MUST BE"
305   PRINT "ENTERED FIRST.  THEN ENTER THE REMAINING OBSERVATIONS IN ORDER OF"
310   PRINT "INCREASING PROTON ENERGY."
315   FOR I=1 TO N2
320   PRINT LIN(1),"OBSERVATION #",I
325   PRINT "PROTON ENERGY (>MEV) =",
330   INPUT E2(I)
335   PRINT E2(I)
340   PRINT "PROTON FLUENCE (PROTONS/CM^2) =",
345   INPUT R2(I)
350   PRINT R2(I)
355   NEXT I
360   PRINT LIN(1),"CHECK THE ABOVE DATA AGAIN."
365   PRINT "IF CORRECTIONS ARE REQUIRED ENTER 0"
370   PRINT "IF DATA IS CORRECT ENTER ANY OTHER NUMBER"
375   INPUT X
380   IF X=0 THEN 270
385   PRINTER IS 0
390   PRINT LIN(1),"PROTON","FLUENCE","FLUENCE","DIFFERENTIAL"
395   PRINT "ENERGY","(PROTONS/CM^2)","(PROTONS/CM^2","FLUENCE"
400   PRINT "(MEV)","> E-(dE/2)","> E+(dE/2)","(PROTONS/CM^2)"
405   FOR I=1 TO N2-1
410   E2(I)=(E2(I)+E2(I+1))/2
415   PRINT E2(I),R2(I),R2(I+1),R2(I)-R2(I+1)
420   NEXT I
425   N2=N2-1
430   PRINTER IS 16
435   RETURN
440   Shield: ! *****************************************************************************
445   REM THIS SUBROUTINE COLLECTS THE SOLAR CELL SHIELDING DATA FORM THE OPRATOR
450   PRINT LIN(1),"FRONT SHIELD THICKNESS (GM/CM^2) = ",
460   IF T1<0 THEN 450
465   PRINT T1,LIN(1),"REAR SHIELD THICKNESS (GM/CM^2) =",
470   INPUT T2
475   IF T2<0 THEN 465
480   PRINT T2
485   PRINTER IS 0
490   PRINT LIN(1),"FRONT SHIELD THICKNESS (GM/CM^2) = ",T1
495   PRINT "REAR SHIELD THICKNESS (GM/CM^2) =",T2
500   PRINTER IS 16
505   RETURN
```

```
510   Ede: ! **************************************************************************
515   REM THIS SUBROUTINE DETERMINES THE ELECTRON DAMAGE COEFFICIENTS
520   FOR I=0 TO 47
525   FOR J=0 TO 8
530   READ T(I,J)
535   NEXT J
540   NEXT I
545   FOR L=0 TO 1
550   T(0,9)=T1+L*(T2-T1)
555   J=8
560   J=J-1
565   IF T(0,9)<T(0,J) THEN 560
570   FOR I=1 TO 47
575   T(I,9+L)=T(I,J+1)-(T(I,J+1)-T(I,J))*(T(0,J+1)-T(0,9))/(T(0,J+1)-T(0,J))
580   IF T(I,9+L)>0 THEN 590
585   T(I,9+L)=0
590   NEXT I
595   NEXT L
600   PRINTER IS 0
605   PRINT LIN(1),"ELECTRON DAMAGE COEFFICIENTS FOR ISC, VOC AND PMAX"
610   PRINT "ELECTRON","DAMAGE","DAMAGE","NET"
615   PRINT "ENERGY","COEFFICIENT","COEFFICIENT","DAMAGE"
620   PRINT "(MEV)","(FRONT)","(REAR)","COEFFICIENT"
625   FOR I=1 TO N1
630   IF E1(I)<T(1,0) THEN K=1
635   FOR J=1 TO 46
640   IF E1(T)>T(J,0) THEN K=J
645   NEXT J
650   D1(I)=T(K,9)+(T(K+1,9)-T(K,9))*(E1(I)-T(K,0))/(T(K+1,0)-T(K,0))
655   D1(I+N1)=T(K,10)+(T(K+1,10)-T(K,10))*(E1(I)-T(K,0))/(T(K+1,0)-T(K,0))
660   PRINT E1(I),D1(I),D1(I+N1),D1(I)+D1(I+N1)
665   NEXT I
670   PRINTER IS 16
675   GOTO 920
680   DATA 0,0,.00559,.0168,.0335,.0671,.112,.168,.335
685   DATA .15,2.69E-4,3.687E-5,0,0,0,0,0,0
690   DATA .16,5E-4,7.951E-5,0,0,0,0,0,0
695   DATA .17,8.951E-4,1.62E-4,0,0,0,0,0,0
700   DATA .18,1.55E-3,3.168E-4,2.227E-5,0,0,0,0,0
705   DATA .19,2.406E-3,5.938E-4,5.228E-5,0,0,0,0,0
710   DATA .2,3.65E-3,1.045E-3,1.143E-4,0,0,0,0,0
715   DATA .22,6.75E-3,2.533E-3,4.375E-4,1.551E-5,0,0,0,0
720   DATA .24,1.035E-2,4.924E-3,1.263E-3,8.667E-5,0,0,0,0
725   DATA .26,1.45E-2,7.981E-3,2.814E-3,3.609E-4,0,0,0,0
730   DATA .28,2.01E-2,1.174E-2,5.0552E-3,1.073E-3,0,0,0,0
735   DATA .3,2.725E-2,1.668E-2,7.941E-3,2.4E-3,2.828E-5,0,0,0
740   DATA .32,3.385E-2,2.249E-2,1.156E-2,4.22E-3,1.481E-4,0,0,0
745   DATA .36,5.004E-2,3.581E-2,2.142E-2,9.858E-3,1.314E-3,0,0,0
750   DATA .4,7E-2,5.255E-2,3.423E-2,1.855E-2,4.311E-3,9.075E-5,0,0
755   DATA .45,9.506E-2,7.562E-2,5.344E-2,3.258E-2,1.106E-2,1.295E-3,0,0
760   DATA .5,1.25E-1,1.023E-1,7.595E-2,5.059E-2,2.146E-2,4.824E-3,7.759E-5,0
```

```
765  DATA .6,2E-1,1.703E-1,1.343E-1,9.816E-2,5.347E-2,2.158E-2,4.315E-3,0
770  DATA .7,2.7E-1,2.4E-1,.2004,.1574,.09769,.04962,.01802,0
775  DATA .8,.35,.3166,.2718,.2225,.1527,.09074,.04262,.00030[illegible]7
780  DATA .9,.4225,.3898,.3438,.291,.2121,.1385,.07726,.004452
785  DATA 1.0,.5,.4657,.4169,.3607,.2759,.1934,.1199,.01566
790  DATA 1.2,.67,.6303,.5733,.5072,.4068,.3081,.2172,.05937
795  DATA 1.4,.86,.816,.7515,.6759,.5593,.4419,.3312,.1281
800  DATA 1.6,1.06,1.012,.9405,.8564,.7256,.5916,.4614,.212
805  DATA 1.8,1.26,1.21,1.136,1.045,.9022,.7521,.604,.3099
810  DATA 2.0,1.47,1.418,1.339,1.242,1.088,.9245,.7611,.4236
815  DATA 2.25,1.729,1.676,1.592,1.489,1.323,1.145,.9639,.5793
820  DATA 2.5,2.0,1.943,1.854,.1.744,1.566,1.374,1.178,.7499
825  DATA 2.75,2.252,2.197,2.108,1.997,1.813,1.611,1.399,.9314
830  DATA 3.0,2.51,2.454,2.362,2.248,2.057,1.847,1.627,1.125
835  DATA 3.25,2.754,2.698,2.606,2.49,2.295,2.078,1.849,1.32
840  DATA 3.5,3.0,2.943,2.85,2.731,2.531,2.309,2.072,1.52
845  DATA 3.75,3.249,3.191,3.096,2.974,2.77,2.541,2.296,1.723
850  DATA 4.0,3.5,3.422,3.344,3.22,3.011,2.775,2.523,1.928
855  DATA 4.5,3.95,3.894,3.798,3.675,3.464,3.223,2.962,2.332
860  DATA 5.0,4.4,4.344,4.247,4.121,3.905,3.659,3.39,2.738
865  DATA 5.5,4.85,4.793,4.695,4.566,4.346,4.093,3.817,3.141
870  DATA 6.0,5.3,5.243,5.143,5.012,4.787,4.528,4.244,3.545
875  DATA 7.0,6.15,6.093,5.992,5.859,5.627,5.358,5.062,4.326
880  DATA 8.0,6.9,6.848,6.753,6.626,6.401,6.138,5.844,5.097
885  DATA 9.0,7.607,7.555,7.462,7.335,7.112,6.848,6.553,5.801
890  DATA 10.0,8.3,8.249,8.156,8.029,7.804,7.539,7.241,6.479
895  DATA 15.0,10.6,10.56,10.49,10.39,10.2,9.981,9.725,9.047
900  DATA 20.0,12.3,12.27,12.21,12.13,11.97,11.77,11.55,10.95
905  DATA 25.0,13.6,13.57,13.52,13.44,13.29,13.11,12.9,12.33
910  DATA 30.0,14.7,14.67,14.62,14.55,14.42,14.25,14.05,13.52
915  DATA 40.0,16.5,16.48,16.43,16.37,16.25,16.1,15.93,15.44
920  RETURN
925  Iscpdc: ! ****************************************************************************
930  REM THIS SUBROUTINE DETERMINES THE PROTON DAMAGE COEFFICIENTS FOR ISC
935  FOR I=0 TO 65
940  FOR J=0 TO 8
945  READ T(I,J)
950  NEXT J
955  NEXT I
960  FOR L=0 TO 1
965  T(0,9)=T1+L*(T2-T1)
970  J=8
975  J=J-1
980  IF T(0,9)<T(0,J) THEN 975
985  FOR I=1 TO 65
990  T(I,9+L)=T(I,J+1)-(T(I,J+1)-T(I,J))*(T(0,J+1)-T(0,9))/(T(0,J+1)-T(0,J))
995  IF T(I,9+L)>0 THEN 1005
1000 T(I,9+L)=0
1005 NEXT I
1010 NEXT L
1015 PRINTER IS 0
```

```
1020 PRINT LIN(1),"PROTON DAMAGE COEFFICIENTS FOR ISC ONLY"
1025 PRINT "PROTON","DAMAGE","DAMAGE","NET"
1030 PRINT "ENERGY","COEFFICIENT","COEFFICIENT","DAMAGE"
1035 PRINT "(MEV)","(FRONT)","(REAR)","COEFFICIENT"
1040 FOR I=1 TO N2
1045 IF E2(I)<T(1,0) THEN K=1
1050 FOR J=1 TO 64
1055 IF E2(I)>=T(J,0) THEN K=J
1060 NEXT J
1065 D2(I)=T(K,9)+(T(K+1,9)-T(K,9))*(E2(I)-T(K,0))/(T(K+1,0)-T(K,0))
1070 D2(I+N2)=T(K,10)+(T(K+1,10)-T(K,10))*(E2(I)-T(K,0))/(T(K+1,0)-T(K,0))
1075 PRINT E2(I),D2(I),D2(I+N2),D2(I)+D2(I+N2)
1080 NEXT I
1085 PRINTER IS 16
1090 GOTO 1425
1095 DATA 0,0,.00559,.0168,.0335,.0671,.112,.168,.335
1100 DATA .1,2.435E-4,0,0,0,0,0,0,0
1105 DATA .2,3.047E-3,0,0,0,0,0,0,0
1110 DATA .3,1.374E-2,0,0,0,0,0,0,0
1115 DATA .4,3.987E-2,0,0,0,0,0,0,0
1120 DATA .6,1.502E-1,0,0,0,0,0,0,0
1125 DATA .8,3.243E-1,0,0,0,0,0,0,0
1130 DATA 1,5.216E-1,0,0,0,0,0,0,0
1135 DATA 1.2,7.108E-1,0,0,0,0,0,0,0
1140 DATA 1.3,7.89E-1,2.322E-5,0,0,0,0,0,0
1145 DATA 1.4,8.549E-1,3.75E-3,0,0,0,0,0,0
1150 DATA 1.6,9.532E-1,8.124E-2,0,0,0,0,0,0
1155 DATA 1.8,1.01,.2525,0,0,0,0,0,0
1160 DATA 2,1.03,.4558,0,0,0,0,0,0
1165 DATA 2.2,1.048,.6233,0,0,0,0,0,0
1170 DATA 2.4,1.041,.7426,0,0,0,0,0,0
1175 DATA 2.6,1.023,.8207,1.86E-5,0,0,0,0,0
1180 DATA 2.8,.9962,.868,.03925,0,0,0,0,0
1185 DATA 3,.9639,.8912,.1794,0,0,0,0,0
1190 DATA 3.2,.9286,.8962,.3465,0,0,0,0,0
1195 DATA 3.4,.8937,.8871,.4807,0,0,0,0,0
1200 DATA 3.6,.8598,.8697,.5787,0,0,0,0,0
1205 DATA 3.8,.8273,.8481,.6459,0,0,0,0,0
1210 DATA 4,.7963,.8243,.6879,1.288E-3,0,0,0,0
1215 DATA 4.2,.7723,.7989,.7105,.07227,0,0,0,0
1220 DATA 4.4,.7486,.7734,.7189,.2077,0,0,0,0
1225 DATA 4.6,.7254,.7499,.7184,.3274,0,0,0,0
1230 DATA 4.8,.7029,.728,.712,.4191,0,0,0,0
1235 DATA 5.2,.6605,.6866,.6890,.5286,0,0,0,0
1240 DATA 5.6,.6216,.6479,.6613,.5723,0,0,0,0
1245 DATA 6,.5867,.6119,.6319,.5839,2.132E-3,0,0,0
1250 DATA 6.4,.5585,.5792,.6019,.5793,.1742,0,0,0
1255 DATA 6.8,.5339,.552,.5731,.5664,.3196,0,0,0
1260 DATA 7.2,.5128,.5285,.5477,.5491,.3945,0,0,0
1265 DATA 7.6,.4947,.5086,.5255,.5299,.4317,0,0,0
1270 DATA 8,.4786,.4909,.5058,.5118,.4484,0,0,0
```

```
1275 DATA 9,.4476,.4565,.4669,.4724,.4478,.2735,0,0
1280 DATA 10,.4337,.4369,.4401,.4425,.4292,.3537,0,0
1285 DATA 11,.4232,.4245,.4258,.4226,.4101,.3675,.2061,0
1290 DATA 12,.4196,.4187,.4155,.411,.3956,.3649,.2839,0
1295 DATA 13,.4185,.4167,.412,.404,.3872,.3588,.3062,0
1300 DATA 14,.4181,.4159,.4015,.402,.3828,.3553,.3131,0
1305 DATA 15,.4194,.4173,.4104,.401,.3814,.3538,.3159,0
1310 DATA 16,.4214,.4182,.412,.4025,.3819,.3547,.3187,.1439
1315 DATA 18,.4192,.4179,.4133,.4054,.3873,.3606,.3269,.2175
1320 DATA 20,.4172,.4159,.4125,.4055,.39,.3679,.3379,.2441
1325 DATA 22,.4144,.4117,.4093,.4047,.3915,.3731,.3473,.2648
1330 DATA 24,.4094,.4083,.4059,.401,.3919,.3757,.3547,.2834
1335 DATA 26,.4049,.4039,.4018,.3985,.3898,.3769,.3591,.2984
1340 DATA 28,.4,.3994,.3978,.3939,.3875,.3764,.3613,.3101
1345 DATA 30,.3935,.393,.3918,.3896,.3834,.3753,.3625,.3186
1350 DATA 34,.3784,.3782,.3777,.3767,.3739,.3677,.36,.3291
1355 DATA 38,.3664,.3662,.3657,.365,.3617,.3582,.3529,.3312
1360 DATA 42,.3532,.3532,.3532,.353,.3519,.3484,.3446,.3292
1365 DATA 46,.3399,.3399,.34,.34,.3396,.3372,.3349,.3245
1370 DATA 50,.3272,.3272,.3272,.3273,.3271,.3264,.325,.3177
1375 DATA 55,.3125,.3126,.3128,.313,.3133,.3132,.3126,.3082
1380 DATA 60,.2988,.2989,.299,.2992,.2995,.2997,.2995,.2969
1385 DATA 65,.2844,.2846,.285,.2855,.2863,.2871,.2875,.2869
1390 DATA 70,.271,.2712,.2715,.272,.2728,.2736,.2743,.2748
1395 DATA 80,.2474,.2476,.248,.2485,.2494,.2504,.2514,.2531
1400 DATA 90,.2245,.2247,.2251,.2256,.2266,.2277,.2289,.2315
1405 DATA 100,.1997,.1999,.2004,.201,.2022,.2037,.2052,.2089
1410 DATA 130,.1492,.1493,.1496,.1500,.1509,.1519,.153,.156
1415 DATA 160,.1183,.1183,.1185,.1188,.1192,.1199,.1206,.1226
1420 DATA 200,.09215,.0922,.09229,.09242,.09268,.09302,.09344,.09462
1425 RETURN
1430 Vocpdc: ! ******************************************************************************
1435 REM THIS SUBROUTINE DETERMINES PROTON DAMAGE COEFFICIENTS FOR VOC & PMAX
1440 FOR I=0 TO 65
1445 FOR J=0 TO 8
1450 READ T(I,J)
1455 NEXT J
1460 NEXT I
1465 FOR L=0 TO 1
1470 T(0,9)=T1+L*(T2-T1)
1475 J=8
1480 J=J-1
1485 IF T(0,9)<T(0,J) THEN 1480
1490 FOR I=1 TO 65
1495 T(I,9+L)=T(I,J+1)-(T(I,J+1)-T(I,J))*(T(0,J+1)-T(0,9))/(T(0,J+1)-T(0,J))
1500 IF T(I,9+L)>0 THEN 1510
1505 T(I,9+L)=0
1510 NEXT I
1515 NEXT L
1520 PRINTER IS 0
1525 PRINT LIN(1),"PROTON DAMAGE COEFFICIENTS FOR VOC & PMAX ONLY"
```

ORIGINAL PAGE IS
OF POOR QUALITY

```
1530 PRINT "PROTON","DAMAGE","DAMAGE","NET"
1535 PRINT "ENERGY","COEFFICIENT","COEFFICIENT","DAMAGE"
1540 PRINT "(MEV)","(FRONT)","(REAR)","COEFFICIENT"
1545 FOR I=1 TO N2
1550 IF E2(I)<T(1,0) THEN K=1
1555 FOR J=1 TO 64
1560 IF E2(I)>=T(J,0) THEN K=J
1565 NEXT J
1570 D3(I)=T(K,9)+(T(K+1,9)-T(K,9))*(E2(I)-T(K,0))/(T(K+1,0)-T(K,0))
1575 D3(I+N2)=T(K,10)+(T(K+1,10)-T(K,10))*(E2(I)-T(K,0))/(T(K+1,0)-T(K,0))
1580 PRINT E2(I),D3(I),D3(I+N2),D3(I)+D3(I+N2)
1585 NEXT I
1590 PRINTER IS 16
1595 GOTO 1930
1600 DATA 0,0,.00559,.0168,.0335,.0671,.112,.168,.335
1605 DATA .1,.5303,0,0,0,0,0,0,0
1610 DATA .2,.715,0,0,0,0,0,0,0
1615 DATA .3,.8623,0,0,0,0,0,0,0
1620 DATA .4,.9976,0,0,0,0,0,0,0
1625 DATA .6,1.271,0,0,0,0,0,0,0
1630 DATA .8,1.546,0,0,0,0,0,0,0
1635 DATA 1,1.792,0,0,0,0,0,0,0
1640 DATA 1.2,1.994,0,0,0,0,0,0,0
1645 DATA 1.3,2.082,.04303,0,0,0,0,0,0
1650 DATA 1.4,2.16,1.948,0,0,0,0,0,0
1655 DATA 1.6,2.299,.5853,0,0,0,0,0,0
1660 DATA 1.8,2.412,.9827,0,0,0,0,0,0
1665 DATA 2,2.502,1.335,0,0,0,0,0,0
1670 DATA 2.2,2.569,1.624,0,0,0,0,0,0
1675 DATA 2.4,2.615,1.86,0,0,0,0,0,0
1680 DATA 2.6,2.645,2.047,.01912,0,0,0,0,0
1685 DATA 2.8,2.656,2.191,.2733,0,0,0,0,0
1690 DATA 3,2.64,2.298,.6092,0,0,0,0,0
1695 DATA 3.2,2.597,2.375,.9375,0,0,0,0,0
1700 DATA 3.4,2.526,2.416,1.226,0,0,0,0,0
1705 DATA 3.6,2.426,2.42,1.468,0,0,0,0,0
1710 DATA 3.8,2.302,2.388,1.664,0,0,0,0,0
1715 DATA 4,2.159,2.32,1.818,.04687,0,0,0,0
1720 DATA 4.2,2.024,2.219,1.932,.2866,0,0,0,0
1725 DATA 4.4,1.891,2.093,1.998,.5697,0,0,0,0
1730 DATA 4.6,1.766,1.962,2.017,.8378,0,0,0,0
1735 DATA 4.8,1.65,1.839,1.99,1.074,0,0,0,0
1740 DATA 5.2,1.447,1.616,1.833,1.431,0,0,0,0
1745 DATA 5.6,1.278,1.428,1.642,1.603,0,0,0,0
1750 DATA 6,1.136,1.268,1.467,1.584,.03741,0,0,0
1755 DATA 6.4,1.02,1.131,1.312,1.468,.451,0,0,0
1760 DATA 6.8,.9237,1.018,1.178,1.339,.8464,0,0,0
1765 DATA 7.2,.844,.9252,1.063,1.218,1.101,0,0,0
1770 DATA 7.6,.7775,.8479,.9673,1.109,1.166,0,0,0
1775 DATA 8,.7204,.7827,.8867,1.013,1.125,.03696,0,0
1780 DATA 8,.6134,.658,.7324,.8256,.9523,.7614,0,0
```

```
1785  DATA 10,.5554,.5834,.6303,.6965,.7998,.8423,0,0
1790  DATA 11,.5169,.5351,.5691,.6105,.6851,.7463,.5746,0
1795  DATA 12,.4936,.5051,.5264,.558,.6035,.6552,.6555,0
1800  DATA 13,.4778 .4859,.4997,.5182,.5493,.583,.6044,0
1805  DATA 14,.4663,.4722,.4815,.4934,.5121,.532,.5496,0
1810  DATA 15,.4594,.4637,.4688,.4758,.4867,.4961,.5047,0
1815  DATA 16,.4548,.4572,.4606,.4642,.4685,.4713,.4327,.3956
1820  DATA 18,.4433,.4458,.448,.4493,.4478,.4419,.4327,.3956
1825  DATA 20,.4352,.4367,.4382,.4379,.4343,.4269,.4142,.3698
1830  DATA 22,.4286,.4278,.429,.4293,.425,.4172,.4041,.3569
1835  DATA 24,.4211,.4211,.4213,.4203,.4176,.4097,.3981,.353
1840  DATA 26,.4146,.4144,.4141,.4137,.4102,.4035,.3931,.3524
1845  DATA 28,.4081,.4081,.4079,.4063,.4040,.3978,.3684,.3527
1850  DATA 30,.4004,.4005,.4003,.3998,.3969,.3926,.3843,.353
1855  DATA 34,.3836,.3838,.3840,.3839,.3831,.3797,.3749,.352
1860  DATA 38,.3703,.3704,.3704,.3703,.3686,.3669,.3636,.3473
1865  DATA 42,.3564,.3565,.3569,.3572,.3571,.3549,.3526,.3409
1870  DATA 46,.3426,.3426,.3429,.3433,.3436,.3421,.3409,.3334
1875  DATA 50,.3296,.3296,.3298,.3301,.3304,.3303,.3297,.3245
1880  DATA 55,.3145,.3145,.3147,.3151,.3158,.3161,.3161,.3132
1885  DATA 60,.3005,.3006,.3007,.3010,.3016,.3020,.3022,.3007
1890  DATA 65,.2859,.2861,.2865,.287,.288,.289,.2897,.2899
1895  DATA 70,.2724,.2726,.2729,.2733,.2743,.2753,.2761,.2773
1900  DATA 80,.2481,.2483,.2487,.2492,.2501,.2512,.2523,.2543
1905  DATA 90,.2249,.2251,.2255,.226,.227,.2281,.2294,.232
1910  DATA 100,.1999,.2001,.2006,.2013,.2025,.2039,.2055,.2092
1915  DATA 130,.1492,.1493,.1496,.15,.1509,.1519,.153,.156
1920  DATA 160,.1183,.1183,.1185,.1188,.1192,.1199,.1206,.1226
1925  DATA 200,.09215,.0922,.09229,.09242,.09268,.09302,.09344,.09462
1930  RETURN
1935  Flucal: ! ***********************************************************************
1940  REM THIS SUBROUTINE USES THE PREVIOUSLY DETERMINED CHARGED PARTICLE
1945  REM FLUENCES & DAMAGE COEFFICIENTS TO CALCULATE THE 1MEV EQUIVALENT FLUENCE
1950  F1=0
1955  FOR I=1 TO N1
1960  F1=(R1(I)-R1(I+1))*(D1(I)+D1(I+N1))+F1
1965  NEXT I
1970  F2=0
1975  F3=0
1980  FOR I=1 TO N2
1985  F2=(R2(I)-R2(I+1))*(D2(I)+D2(I+N2))+F2
1990  F3=(R2(I)-R2(I+1))*(D3(I)+D3(I+N2))+F3
1995  NEXT I
2000  PRINTER IS 0
2005  PRINT LIN(1),"SOLAR CELL","ELECTRON RADIATION","PROTON RADIATION","NET RADI
ATION"
2010  PRINT "DEGRADATION","EQUIVALENT FLUENCE","EQUIVALENT FLUENCE","EQUIVALENT F
LUENCE"
2015  PRINT "PARAMETER","1MEV ELECTRONS/CM^2","10MEV PROTONS/CM^2","1MEV ELECTRON
S/CM^2"
2020  PRINT "ISC",F1,F2,F1+3000*F2
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2025 PRINT "VOC & PMAX",F1,F3,F1+3000*F3,LIN(3)
2030 PRINTER IS 16
2035 RETURN
```

Appendix B – IVDEG

```
5    REM********************************** IVDEG ****************************************
10   REM THIS PROGRAM CALCULATES THE AMOUNT OF DEGRADATION IN THE I-V
15   REM PARAMETERS OF A SILICON SOLAR CELL IRRADIATED WITH 1 MEV ELECTRONS
20   REM AT NORMAL INCIDENT.
25   OPTION BASE 0
30   DIM Y(10,14),X(6),Isc(2),Voc(2),Pmax(2).Vmp(2),Imp(2)
35   GOSUB Input
40   GOSUB Temco
45   GOSUB Unrad
50   GOSUB Degrad
55   GOSUB Irrad
60   GOSUB Plot
65   STOP
70   Input: ! ************************************************************************
75   REM THIS SUBROUTINE COLLECTS INFORMATION ABOUT THE SOLAR CELL FROM THE
80   REM OPERATOR
85   PRINT (LIN(2),"I-V PARAMETERS BEFORE IRRADIATION:",LIN(1),SPA(4),"Isc (mA) ="
;
90   INPUT Isc(0)
95   PRINT Isc(0),LIN(1),SPA(4),"Voc (mV) =";
100  INPUT Voc(0)
105  PRINT Voc(0),LIN(1),SPA(4),"Imp (mA) =";
110  INPUT Imp(0)
115  PRINT Imp(0),LIN(1),SPA(4),"Vmp (mV) =";
120  INPUT Vmp(0)
125  PRINT Vmp(0),LIN(1),SPA(4),"CELL TEMPERATURE ('C) =";
130  INPUT Tem
135  PRINT Tem,LIN(1),SPA(4),"CELL THICKNESS (CM) =";
140  INPUT T
145  PRINT T,LIN(1),SPA(4),"ACTIVE CELL AREA (CM^2) =";
150  INPUT A
155  PRINT A,LIN(1),SPA(4),"CELL RESISTIVITY (OHM-CM) =";
160  INPUT Res
165  PRINT Res,LIN(3),"CELL TYPE:"
170  PRINT SPA(4),"ENTER '1' FOR CONVENTIONAL AND SHALLOW JUNCTION CELL"
175  PRINT SPA(4),"ENTER '2' FOR CELL WITH BACK SURFACE REFLECTOR (BSR)"
180  PRINT SPA(4),"ENTER '3' FOR CELL WITH BSR AND BACK SURFACE FIELD (BSF)"
185  INPUT Dum
190  Dum=INT(Dum)
195  IF Dum<1 THEN 165
200  IF Dum>3 THEN 165
205  PRINT "CELL TYPE";Dum,LIN(3),"IRRADIATION DOSE:"
210  PRINT "EQUIVALENT FLUENCE FOR Isc DEGRADATION (1MEV ELECTRONS/CM^2) =";
215  INPUT Fsc
220  PRINT Fsc
225  PRINT "EQUIVALENT FLUENCE FOR Voc DEGRADATION (1MEV ELECTRONS/CM^2 = ";
230  INPUT Foc
235  PRINT Foc,LIN(2)
240  RETURN
```

```
245   Temco: ! ************************************************************************
250   REM THIS SUBROUTINE DETERMINES THE TEMPERATURE COEFFICIENTS FOR EACH
255   REM I-V PARAMETER OF THE IRRADIATED AND UNIRRADIATED CELLS
260   FOR I=1 TO 8
265   READ Y(I,0),Y(I,1),Y(I,2),Y(I,4),Y(I,5),Y(I,7),Y(I,8),Y(I,10),Y(I,11)
270   FOR J=1 TO 10 STEP 3
275   Y(I,J+2)=Y(I,J)+(Res-2)*(Y(I,J+1)-Y(I,J))/8
280   NEXT J
285   NEXT I
290   FOR I=1 TO 7
295   IF Fsc<Y(I,0) THEN 305
300   Y(0,3)=Y(I,3)+(Fsc-Y(I,0))*(Y(I+1,3)-Y(I,3))/(Y(I+1,0)-Y(I,0))
305   NEXT I
310   FOR J=6 TO 12 STEP 3
315   FOR I=1 TO 7
320   IF Foc<Y(I,0) THEN 335
325   Y(0,J)=Y(I,J)+(Foc-Y(I,0))*(Y(I+1,J)-Y(I,J))/(Y(I+1,0)-Y(I,0))
330   NEXT I
335   NEXT J
340   GOTO 385
345   DATA 0,.0182,.0182,-2.01,-2.256,-.054,-.0723,-1.976,-2.296
350   DATA 1E+12,.0166,.0185,-1.979,-2.248,-.0535,-.072,-1.921,-2.235
355   DATA 1E+13,.019,.0222,-1.97,-2.255,-.052,-.0692,-1.9,-2.21
360   DATA 3E+13,.021,.0286,-2.009,-2.25,-.0498,-.0651,-1.875,-2.208
365   DATA 1E+14,.0265,.0395,-2.099,-2.254,-.0461,-.058,-1.898,-2.21
370   DATA 3E+14,.0325,.0482,-2.192,-2.259,-.0416,-.052,-1.918,-2.216
375   DATA 1E+15,.035,.0515,-2.259,-2.275,-.0376,-.0417,-1.98,-2.24
380   DATA 1E+16,.0415,.06,-2.302,-2.309,-.0279,-.0361,-2.049,-2.326
385   RETURN
390   Unrad: ! ************************************************************************
395   REM THIS SUBROUTINE DETERMINES THE CHARACTERISTICS OF THE UNRADIATED CELL
400   Isc(0)=Isc(0)+A*Y(1,3)*(30-Tem)
405   Voc(0)=Voc(0)+Y(1,6)*(30-Tem)
410   Pmax(0)=Imp(0)*Vmp(0)+1E-3+A*Y(1,9)*(30-Tem)
415   Bmax=(1.5+(1/3-1.5)*(Res-2)/8)*1E-5
420   Pmax(0)=Pmax(0)/(1+Bmax*(30-Tem)*(30-Tem)/2)
425   Vmp(0)=Vmp(0)+Y(1,12)*(30-Tem)
430   IF Tem>-20 THEN GOTO 445
435   Voc(0)=Voc(0)-Y(1,6)*(30-Tem)+50*Y(1,6)-(Y(1,5)-.005*(Tem+20)/2)*(Tem+20)
440   Vmp(0)=Vmp(0)-Y(1,12)*(30-Tem)+50*Y(1,12)-(Y(1,12)-.005*(Tem+20)/2)*(Tem+20)
445   Imp(0)=1E3*Pmax(0)/Vmp(0)
450   PRINTER IS 0
445   PRINT LIN(2),"CELL TYPE"
460   IF Dum=1 THEN PRINT "A CONVENTIONAL AND SHALLOW JUNCTION N/P SILICON SOLAR C
ELL"
465   IF Dum=2 THEN PRINT "A N/P SILICON SOLAR CELL WITH BSR"
470   IF Dum=3 THEN PRINT "A N/P SILICON SOLAR CELL WITH BSR AND BSF"
475   PRINT "CELL RESISTIVITY =";Res;"OHM-CM"
480   PRINT "CELL THICKNESS =";T;"CM",LIN(1),"ACTIVE CELL AREA =";A;"CM^2"
485   PRINT LIN(2),"I-V CHARACTERISTICS OF THE UNIRRADIATED CELL"
490   PRINT "Isc =";Isc(0);"mA +";A*Y(1,3);"mA/'C * (T-30'C)"
```

```
495   PRINT "Voc =";Voc(0);"mV";Y(1,6);"mV/'C * (T-30'C)"
500   PRINT "Pmax = ";Pmax(0);"mW";A*Y(1,9);"mW/'C * (T-30'C)"
505   PRINT "Vmp = ";Vmp(0);"mV";Y(1,12);"mV/'C * (T-30'C)"
510   PRINT "Imp = Pmax/Vmp"
515   PRINTER IS 16
520   RETURN
525   Degrad: ! ***********************************************************************
530   REM THIS SUBROUTINE DETERMINES THE DEGRADATION IN THE I-V CURVE AT 28'C
535   FOR I=1 TO 3
540   READ T1,T2
545   FOR J=1 TO 4
550   READ B1,B2,B3,B4
555   B5=B1+(B2-B1)*(T-T1)/(T2-T1)
560   B6=B3+(B4-B3)*(T-T1)/(T2-T1)
565   Fe(I,J)=B5+(B6-B5)*(Res-2)/(10-2)
570   NEXT J
575   NEXT I
580   C(1)=-1*Isc(0)/LGT(2)
585   C(2)=-.1*Voc(0)/LGT(2)
590   C(3)=-.1*Pmax(0)/LGT(2)
595   C(4)=-.1*Vmp(0)/LGT(2)
600   PRINTER IS 0
605   PRINT LIN(2),"DEGRADATION EQUATION FOR EACH I-V PARAMETER"
610   PRINT "Isc(F)=";Isc(0);"mA";C(1);"*LOG(1+F/";Fe(Dum,1);"1MEV e-/CM^2)"
615   PRINT "Voc(F)=";Voc(0);"mV";C(2);"*LOG(1+F/";Fe(Dum,2);"1MEV e-/CM^2)"
620   PRINT "Pmax(F)=";Pmax(0);"mW";C(3);"*LOG(1+F/";Fe(Dum,3);"1MEV e-/CM^2)"
625   PRINT "Vmp(F)=";Vmp(0);"mV";C(4);"*LOG(1+F/";Fe(Dum,4);"1MEV e-/CM^2)"
630   PRINT "Imp(F) = Pmax(F)/Vmp(F)"
635   PRINTER IS 16
640   GOTO 690
645   DATA .02,.03,1.6E+14,1.6E+14,8.2E+14,4.5E+14
650   DATA 1E+15,1E+15,3E+15,2E+15,7.4E+13,7.4E+13
655   DATA 2.9E+14,1.5E+14,1E+15,1E+15,1.8E+15,1E+15
660   DATA .01,.02,4.5E+14,2.3E+14,1.3E+15,4.5E+14
665   DATA 3E+15,1.3E+15,6.2E+15,2.1E+15,2.3E+14,1.15E+14
670   DATA 5.8E+14,2E+14,2.4E+15,1.1E+15,3.2E+15,1.3E+15
675   DATA .01,.02,1.15E+14,7E+13,3.5E+14,1.5E+14
680   DATA 3.8E+14,4.5E+14,1.9E+14,1.3E+14,4.8E+13,3.4E+13
685   DATA 8E+13,3.6E+13,3.3E+14,2.6E+14,2E+14,1.2E+14
690   RETURN
695   Irrad: ! ***********************************************************************
700   REM THIS SUBROUTINE DETERMINES THE CHARACTERISTICS OF THE IRRADIATED CELL
705   Isc(1)=Isc(0)+C(1)*LGT(1+Fsc/Fe(Dum,1))
710   Voc(1)=Voc(0)+C(2)*LGT(1+Foc/Fe(Dum,2))
715   Pmax(1)=Pmax(0)+C(3)*LGT(1+Foc/Fe(Dum,3))
720   Vmp(1)=Vmp(0)+C(4)*LGT(1+Foc/Fe(Dum,4))
725   Imp(1)=1E3*Pmax(1)/Vmp(1)
730   PRINTER IS 0
735   PRINT LIN(2),"RADIATION DOSAGE"
740   PRINT "EQUIVALENT FLUENCE FOR Isc =";Fsc;"1MEV ELECTRON' 'M^2"
745   PRINT "EQUIVALENT FLUENCE FOR Voc, Pmax & Vmp =";Foc;"1MEV ELECTRONS/CM^2"
```

```
750   PRINT LIN(2),"I-V CHARACTERISTICS OF THE IRRADIATED CELL"
755   PRINT "Isc =";Isc(1);"mA +";A*Y(0,3);"mA/'C * (T-30'C)"
760   PRINT "Voc =";Voc(1);"mV";Y(0,6);"mV/'C * (T-30'C)"
765   PRINT "Pmax =";Pmax(1);"mW";A*Y(0,9);"mW/'C * (T-30'C)"
770   PRINT "Vmp =";Vmp(1);"mV";Y(0,12);"mV/'C * (T-30'C)"
775   PRINT "Imp = Pmax/Vmp"
780   PRINTER IS 16
785   RETURN
790   Plot: ! ****************************************************************************
795   REM THIS SUBROUTINE PLOTS A FAMILY OF I-V CURVES FOR THE IRRADIATED
800   REM AND UNIRRADIATED CELLS
805   PLOTTER IS 13,"GRAPHICS"
810   GRAPHICS
815   LOCATE 1,120,1,90
820   Xmax=100*(1+INT((Voc(0)+Y(1,6)*-60)/100))
825   Ymax=25*(1+INT((Isc(0)+A*Y(1,3)*60)/25))
830   SCALE -Xmax/10,Xmax,-Ymax/10,Ymax
835   AXES 10,5,0,0,10,5
840   FOR K=0 TO 1
845   FOR Tc=90 TO -30 STEP -60
850   CSIZE 3
855   LDIR 0
860   LORG 5
865   X(1)=Isc(K)+A*Y(1-K,3)*(Tc-30)
870   X(2)=Voc(K)+Y(1-K,6)*(Tc-30)
875   Bmax=1.5+(1/3-1.5)*(Res-2)/8)*1E-5
880   X(3)=(Pmax(K)+A*Y(1-K,9)*(Tc-30))/(1+Bmax*(Tc-30)*(Tc-30)/2)
885   X(4)=Vmp(K)+Y(1-K,12)*(Tc-30)
890   IF Tc>-20 THEN GOTO 905
895   X(2)=Voc(K)-50*Y(1-K,6)*(Y(1-K,6)-.005*(Tc+20)/2)*(Tc+20)
900   X(4)=Vmp(K)-50*Y(1-K,12)*(Y(1-K,12)-.005*(Tc+20)/2)*(Tc+20)
905   X(5)=1E3*X(3)/X(4)
910   MOVE 0,X(1)
915   FOR Vol=0 TO INT(X(2))
920   C2=(X(4)/X(2)-1)/LOG(1-X(5)/X(1))
925   C1=(1-X(5)/X(1))*EXP(-X(4)/(C2*X(2)))
930   Cur=X(1)*(1+C1*(1-EXP(Vol/(C2*X(2)))))
935   PLOT Vol,Cur
940   NEXT Vol
945   MOVE X(4),X(5)
950   CSIZE 3
955   LABEL "*"
960   LORG 3
965   CSIZE 2
970   MOVE Xmax/100,X(1)-Ymax/195
975   LABEL "T =";Tc;"C"
980   NEXT Tc
985   NEXT K
990   REM LABEL VOLTAGE AXES
995   CSIZE 3
1000  LORG 5
```

```
1005 FOR I=0 TO Xmax STEP 100
1010 MOVE I,-Ymax/30
1015 LABEL I
1020 NEXT I
1025 MOVE Xmax/2,-Ymax/15
1030 LABEL "VOLTAGE (mV)"
1035 REM LABEL CURRENT AXES
1040 LORG 8
1045 FOR I=0 TO Ymax STEP 25
1050 MOVE -Xmax/50,I
1055 LABEL I
1060 NEXT I
1065 DEG
1070 LDIR 90
1075 LORG 6
1080 MOVE -Xmax/10,Ymax/2
1085 LABEL "CURRENT (mA)"
1090 DUMP GRAPHICS
1095 EXIT GRAPHICS
1100 PRINTER IS 0
1105 PRINT LIN(4)
1110 PRINTER IS 16
1115 RETURN
```

Appendix C – IUEPOW

```
5     REM ********************************** IUEPOW ***************************************
10    REM THIS PROGRAM CALCULATES THE IUE SOLAR ARRAY POWER VERSUS BETA ANGLE
15    REM FOR EACH YEAR FROM THE BEGINNING OF LIFE TO 10 YEARS.
20    DIM P(136,15),Pl(136,3),Pc(136,3),Pu(136,3)
25    DEG
30    READ Tmin,Tmax
35    FOR Time=Tmin TO Tmax
40    FOR C=1 TO 2
45    READ Ysc,Bsc,Yoc,Boc,Ymax,Bmax,Ymp,Bmp,Fsc,Fop,TO
50    FOR B=0 TO 135
55    REM CALCULATE LOWER PANEL POWER
60    IF B>112 THEN 90
65    Vop=389
70    S=COS(B-22.5)
75    T=37.41513+1.10256*B-.01848*B*B+TO
80    GOSUB Iop
85    Pl(B,C)=48*28*Iop/1000
90    REM CALCULATE CENTRAL PANEL POWER
95    Vop=423
100   S=COS(B-67.5)
105   T=-12.18705+2.13056*B-.01563*B*B+TO
110   GOSUB Iop
115   Pc(B,C)=40*28*Iop/1000
120   REM CALCULATE UPPER PANEL POWER
125   IF B<23 THEN 155
130   Vop=389
135   S=COS(B-112.5)
140   T=-126.3935+3.51306*B-.01652*B*B+TO
145   GOSUB Iop
150   Pu(B,C)=48*28*Iop/1000
155   NEXT B
160   NEXT C
165   FOR B=0 TO 135
170   K=.06661+.01202*B-.00007*B*B
175   P(B,Time)=K*(P1(B,1)+Pc(B,1)+Pu(B,1))+(1-K)*(P1(B,2)+Pc(B,2)+Pu(B,2))
180   NEXT B
185   NEXT Time
190   GOSUB Graph
195   GOSUB Print
200   STOP
205   Iop: ! ****************************************************************************
210   REM THIS SUBROUTINE CALCULATES THE CELL OPERATING CURRENT.
215   Isc=Ysc+Bsc*(T-30)
220   Voc=Yoc+Boc*(T-30)
225   Pmax=(Ymax+Bmax*(T-30))/(1+1.64583E-5*(T-30)*(T-30)/2)
230   Vmp=Ymp+Bmp*(T-30)
235   IF T>-20 THEN GOTO 250
240   Voc=Yoc-50*Boc+(Boc-.005*(T+20)/2)*(T+20)
245   Vmp=Ymp-50*Bmp+(Bmp-.005*(T+20)/2)*(T+20)
```

```
250   Imp=1000*Pmax/Vmp
255   C2=(Vmp/Voc-1)/LOG(1-Imp/Isc)
260   C1=(1-Imp/Isc)*EXP(-Vmp/(C2*Voc))
265   Iop=Isc*(1+C1*(1-EXP(Vop/(C2*Voc))))
270   Iop=Fop*(Iop-(Isc-Fsc*S*Isc))
275   IF Iop<0 THEN Iop=0
280   RETURN
285   Graph : ! ***************************************************************************
290   REM THIS SUBROUTINE PLOTS POWER Vs. BETA FOR EACH YEAR.
295   Ymax=50*(1+INT(P(70,Tmin)/50))
300   Ymin=50*INT(P(0,Tmax)/50)
305   PLOTTER IS 13,"GRAPHICS"
310   GRAPHICS
315   LOCATE 1,120,1,90
320   SCALE -15,135,Ymin-(Ymax-Ymin)/10,Ymax
325   AXES 5,10,0,Ymin,9,5
330   REM LABEL BETA AXES
335   LDIR 0
340   CSIZE 3
345   LORG 5
350   FOR I=0 TO 135 STEP 15
355   MOVE I,Ymin-(Ymax-YMin)/30
360   LABEL I
365   NEXT I
370   MOVE 67,Ymin-(Ymax-Ymin)/15
375   LABEL "BETA ANGLE (DEGREES)"
380   REM LABEL POWER AXES
385   LORG 8
390   FOR I=Ymin TO Ymax STEP 50
395   MOVE 0,I
400   LABEL I
405   NEXT I
410   LDIR 90
415   LORG 6
420   MOVE -15,Ymin+(Ymax-Ymin)/2
425   LABEL "POWER (WATTS)"
430   LORG 5
435   LDIR 0
440   CSIZE 2
445   FOR Time=Tmin TO Tmax
450   MOVE 0,P(0,Time)
455   FOR B=0 TO 135
460   PLOTB,P(B,Time)
465   NEXT B
470   NEXT Time
475   DUMP GRAPHICS
480   EXIT GRAPHICS
485   RETURN
490   Print: ! ***************************************************************************
495   REM THIS SUBROUTINE PRINTS A HARD COPY OF THE AVAILABLE POWER AT EACH BETA
500   REM ANGLE FOR EACH YEAR.
```

ORIGINAL PAGE IS
OF POOR QUALITY

```
505     PRINTER IS 0
510     FOR Time=Tmin TO Tmax
515     PRINT LIN(4),"AVAILABLE SOLAR ARRAY POWER AFTER ";Time;" YEARS"
520     FIXED 0
525     PRINT "BETA";TAB(7),"POWER";TAB(19),"BETA";TAB(26),"POWER";TAB(38),"BETA";T
AB(45),"POWER";TAB(57),"BETA";TAB(64),"POWER"
530     PRINT "(DEG)";TAB(7),"(WATTS)";TAB(19),"(DEG)";TAB(26),"(WATTS)";TAB(38),"(
DEG)";TAB(45),"(WATTS)";TAB(57),"(DEG)";TAB(64),"(WATTS)"
535     FOR B=0 TO 132 STEP 4
540     PRINT B;TAB(7),P(B,Time);TAB(19),B+1;TAB(26),P(B+1,Time);TAB(38),B+2;TAB(45
),P(B+2,Time);TAB(57),B+3;TAB(64),P(B+3,Time)
545     NEXT B
550     NEXT Time
555     PRINT LIN(4)
560     PRINTER IS 16
565     RETURN
570     DATA 0,10
575     DATA 140.34,.06734,586.1,-1.979,64.04,-.191,490.32,-1.936,1.035,.958,3.7
580     DATA 137.34,.06734,586.1,-1.979,62.54,-.191,490.32,-1.936,.954,.902,-3.7
585     DATA 131.25,.0777,580.96,-2.57.63,-.174,486.71,-1.84,1.035,.958,3.7
590     DATA 121.02,.0918,574.83,-2.08,51.83,-.165,482.37,-1.86,.954,.902,-3.7
595     DATA 125.00,.0889,576.1,-2.071,53,88,-.166,483.28,-1.857,1.035,.958,3.7
600     DATA 112.2,.1023,564.88,-2.139,47.07,-.156,475.23,-1.871,.954,.902,-3.7
605     DATA 120.24,.0954,571.52,-2.101,51.22,-.162,480.01,-1.863,1.035,.958,3.7
610     DATA 106.12,.1127,555.97,-2.186,43.97,-.1488,468.74,-1.883,.954,.902,-3.7
615     DATA 116.38,.09995,567.16,-2.126,49.16,-.158,476.88,-1.869,1.035,.958,3.7
620     DATA 101.47,.1142,547.92,-2.197,41.67,-.1469,462.8,-1.893,.954,.902,-3.7
625     DATA 113.14,.1045,563.02,-2.15,47.48,-.1543,473.89,-1.874,1.035,.958,3.7
630     DATA 97.71,.1155,540.57,-2.208,39.84,-.145,457.32,-1.903,.954,.902,-3.7
635     DATA 110.35,.1091,559.08,-2.174,46.05,-.1505,471.01,-1.879,1.035,.958,3.7
640     DATA 94.55,.1167,533.81,-2.219,38.31,-.1433,452.23,-1,913,.954,.902,-3.7
645     DATA 107.9,.1131,555.31,-2.187,44.82,-1486,468.25,-1.884,1.035,.958,3.7
650     DATA 91.822,.11798,527.54,-2.231,37.0,-.14148,447.4816,-1.924,.954,.902,-3
.7
655     DATA 105.71,.1136,551.7,-2.192,43.73,-.1478,465.59,-1.888,1.035,.958,3.7
660     DATA 89.43,.1192,521.71,-2.242,35.87,-.1397,443.03,-1.934,.954,.902,-3.7
665     DATA 103.74,.1142,548.24,-2.197,42.76,-.147,463.03,-1.893,1.035,.958,3.7
670     DATA 87.29,.1205,516.26,-2.253,34.86,-.1378,438.85,-1.944,.954,.902,-3.7
675     DATA 101.94,.1148,544.91,-2.2,41.87,-.1462,460.56,-1.897,1.035,.958,3.7
680     DATA 85.36,.1217,511.14,-2.257,33.95,-.1369,434.9,-1.948,.954,.902,-3.7
```

Appendix D – PREDICTED IUE SOLAR ARRAY CHARACTERISTICS

BEST CASE IRRADIATION DOSAGE AND I-V PARAMETERS AT BOL

EQUIVALENT FLUENCE FOR I_{SC} = 0 1Mev e/cm^2

EQUIVALENT FLUENCE FOR V_{OC} AND P_{MAX} = 0 1Mev e/cm^2

I_{SC} = 140.34mA + .0673mA/°C (T-30°C)

V_{OC} = 586.10mV - 1.98mV/°C (T-30°C)

P_{MAX} = 64.04mW - .191mW/°C (T-30°C)

V_{MP} = 490.32mV - 1.94mV/°C (T-30°C)

WORST CASE IRRADIATION DOSAGE AND I-V PARAMETERS AT BOL

EQUIVALENT FLUENCE FOR I_{SC} = 0 1Mev e/cm^2

EQUIVALENT FLUENCE FOR V_{OC} AND P_{MAX} = 0 1Mev e/cm^2

I_{SC} = 137.34 + .0673mA/°C (T-30°C)

V_{OC} = 586.10mV - 1.98mV/°C (T-30°C)

P_{MAX} = 62.54mW - .191mW/°C (T-30°C)

V_{MP} = 490.32mV - 1.94mV/°C (T-30°C)

AVAILABLE SOLAR ARRAY POWER AT BOL

BETA (DEG)	POWER (WATTS)	BETA (DEG)	POWER (WATTS)	BETA (DEG)	POWER (WATTS)	BETA (DEG)	POWER (WATTS)
0	198	1	201	2	205	3	209
4	212	5	215	6	219	7	222
8	225	9	229	10	232	11	235
12	238	13	241	14	243	15	246
16	249	17	251	18	254	19	256
20	259	21	261	22	263	23	267
24	271	25	276	26	281	27	285
28	290	29	294	30	299	31	303
32	307	33	311	34	315	35	319
36	323	37	327	38	330	39	334
40	337	41	340	42	344	43	347
44	350	45	352	46	355	47	358
48	360	49	363	50	365	51	367
52	369	53	371	54	373	55	375
56	376	57	378	58	379	59	380
60	381	61	382	62	383	63	384
64	385	65	385	66	386	67	386
68	386	69	386	70	386	71	386
72	385	73	385	74	384	75	383
76	383	77	382	78	381	79	379
80	378	81	377	82	375	83	373
84	372	85	370	86	368	87	366
88	363	89	361	90	358	91	356
92	353	93	350	94	347	95	344
96	341	97	338	98	334	99	331
100	327	101	324	102	320	103	316
104	312	105	308	106	303	107	299
108	295	109	290	110	286	111	281
112	276	113	273	114	271	115	269
116	267	117	265	118	262	119	260
120	257	121	255	122	252	123	249
124	246	125	244	126	240	127	237
128	234	129	231	130	228	131	224
132	221	133	217	134	214	135	210

BEST CASE IRRADIATION DOSAGE AND I-V PARAMETERS AFTER 1 YEAR

EQUIVALENT FLUENCE FOR I_{SC} = 4.39E+13 1Mev e/cm^2

EQUIVALENT FLUENCE FOR V_{OC} AND P_{MAX} = 4.71E+13 1Mev e/cm^2

I_{SC} = 131.25mA + .0777mA/°C (T-30°C)

V_{OC} = 580.96mV - 2.00mV/°C (T-30°C)

P_{MAX} = 57.63mW - .174mW/°C (T-30°C)

V_{MP} = 486.71mV - 1.87mV/°C (T-30°C)

WORST CASE IRRADIATION DOSAGE AND I-V PARAMETERS AFTER 1 YEAR

EQUIVALENT FLUENCE FOR I_{SC} = 9.90E+13 1Mev e/cm^2

EQUIVALENT FLUENCE FOR V_{OC} AND P_{MAX} = 1.07E+14 1Mev e/cm^2

I_{SC} = 121.02mA + .0918mA/°C (T-30°C)

V_{OC} = 574.83mV - 2.08mV/°C (T-30°C)

P_{MAX} = 51.83mW - .165mW/°C (T-30°C)

V_{MP} = 482.37mV - 1.86mV/°C (T-30°C)

AVAILABLE SOLAR ARRAY POWER AFTER 1 YEAR

BETA (DEG)	POWER (WATTS)	BETA (DEG)	POWER (WATTS)	BETA (DEG)	POWER (WATTS)	BETA (DEG)	POWER (WATTS)
0	173	1	176	2	180	3	183
4	186	5	189	6	192	7	195
8	198	9	201	10	204	11	207
12	210	13	212	14	215	15	217
16	220	17	212	18	225	19	227
20	229	21	231	22	233	23	236
24	240	25	245	26	249	27	253
28	257	29	261	30	265	31	269
32	273	33	276	34	280	35	284
36	287	37	290	38	294	39	297
40	300	41	303	42	306	43	309
44	311	45	314	46	317	47	319
48	321	49	324	50	326	51	328
52	330	53	331	54	333	55	335
56	336	57	337	58	339	59	340
60	341	61	342	62	343	63	343
64	344	65	344	66	345	67	345
68	345	69	345	70	345	71	345
72	345	73	344	74	344	75	343
76	343	77	342	78	341	79	340
80	339	81	337	82	336	83	334
84	333	85	331	86	329	87	327
88	325	89	323	90	321	91	319
92	316	93	314	94	311	95	308
96	306	97	303	98	300	99	296
100	293	101	290	102	286	103	283
104	279	105	276	106	272	107	268
108	264	109	260	110	256	111	252
112	248	113	245	114	243	115	241
116	239	117	237	118	235	119	233
120	231	121	228	122	226	123	223
124	221	125	218	126	216	127	213
128	210	129	207	130	204	131	201
132	198	133	195	134	191	135	188

BEST CASE IRRADIATION DOSAGE AND I-V PARAMETERS AFTER 2 YEARS

EQUIVALENT FLUENCE FOR I_{SC} = 8.78E+13 1Mev e/cm^2
EQUIVALENT FLUENCE FOR V_{OC} AND P_{MAX} = 9.41E+13 1Mev e/cm^2
I_{SC} = 125.00mA + .0889mA/°C (T-30°C)
V_{OC} = 576.10mV - 2.07mV/°C (T-30°C)
P_{MAX} = 53.88mW - .166mW/°C (T-30°C)
V_{MP} = 483.28mV - 1.86mV/°C (T-30°C)

WORST CASE IRRADIATION DOSAGE AND I-V PARAMETERS AFTER 2 YEARS

EQUIVALENT FLUENCE FOR I_{SC} = 1.98E+14 1Mev e/cm^2
EQUIVALENT FLUENCE FOR V_{OC} AND P_{MAX} = 2.14E+14 1Mev e/cm^2
I_{SC} = 112.20mA + .102mA/°C (T-30°C)
V_{OC} = 564.88mV - 2.14mV/°C (T-30°C)
P_{MAX} = 47.07mW - .156mW/°C (T-30°C)
V_{MP} = 475.23mV - 1.87mV/°C (T-30°C)

AVAILABLE SOLAR ARRAY POWER AFTER 2 YEARS

BETA (DEG)	POWER (WATTS)	BETA (DEG)	POWER (WATTS)	BETA (DEG)	POWER (WATTS)	BETA (DEG)	POWER (WATTS)
0	160	1	163	2	166	3	169
4	172	5	175	6	178	7	181
8	184	9	187	10	189	11	192
12	195	13	197	14	200	15	202
16	204	17	207	18	209	19	211
20	213	21	215	22	217	23	220
24	224	25	228	26	232	27	235
28	239	29	243	30	247	31	250
32	254	33	257	34	261	35	264
36	267	37	270	38	274	39	276
40	279	41	282	42	285	43	288
44	290	45	293	46	295	47	297
48	299	49	301	50	303	51	305
52	307	53	309	54	310	55	312
56	313	57	314	58	316	59	317
60	318	61	318	62	319	63	320
64	320	65	321	66	321	67	322
68	322	69	322	70	322	71	322
72	321	73	321	74	321	75	320
76	319	77	319	78	318	79	317
80	316	81	315	82	313	83	312
84	310	85	309	86	307	87	305
88	304	89	302	90	300	91	297
92	295	93	293	94	290	95	288
96	285	97	282	98	280	99	277
100	274	101	271	102	267	103	264
104	261	105	258	106	254	107	250
108	247	109	243	110	239	111	236
112	232	113	229	114	227	115	226
116	224	117	222	118	220	119	218
120	216	121	214	122	211	123	209
124	207	125	204	126	201	127	199
128	196	129	193	130	191	131	188
132	185	133	182	134	179	135	176

BEST CASE IRRADIATION DOSAGE AND I-V PARAMETERS AFTER 3 YEARS

EQUIVALENT FLUENCE FOR I_{SC} = 1.32E+14 1Mev e/cm^2

EQUIVALENT FLUENCE FOR V_{OC} AND P_{MAX} = 1.41E+14 1Mev e/cm^2

I_{SC} = 120.24mA + .0954mA/°C (T-30°C)

V_{OC} = 571.52mV - 2.10mV/°C (T-30°C)

P_{MAX} = 51.22mW - .162mW/°C (T-30°C)

V_{MP} = 480.00mV - 1.86 mV/°C (T-30°C)

WORST CASE IRRADIATION DOSAGE AND I-V PARAMETERS AFTER 3 YEARS

EQUIVALENT FLUENCE FOR I_{SC} = 2.97E+14 1Mev e/cm^2

EQUIVALENT FLUENCE FOR V_{OC} AND P_{MAX} = 3.21E+14 1Mev e/cm^2

I_{SC} = 106.12mA + .113mA/°C (T-30°C)

V_{OC} = 555.97mV - 2.19mV/°C (T-30°C)

P_{MAX} = 43.97mW - .149mW/°C (T-30°C)

V_{MP} = 468.74mV - 1.88mV/°C (T-30°C)

AVAILABLE SOLAR ARRAY POWER AFTER 3 YEARS

BETA (DEG)	POWER (WATTS)	BETA (DEG)	POWER (WATTS)	BETA (DEG)	POWER (WATTS)	BETA (DEG)	POWER (WATTS)
0	151	1	154	2	157	3	160
4	163	5	166	6	169	7	171
8	174	9	177	10	179	11	182
12	184	13	187	14	189	15	191
16	194	17	196	18	198	19	200
20	202	21	204	22	206	23	208
24	212	25	216	26	220	27	223
28	227	29	230	30	234	31	237
32	241	33	244	34	247	35	250
36	253	37	256	38	259	39	262
40	265	41	267	42	270	43	[illegible]
44	275	45	277	46	279	47	282
48	284	49	285	50	287	51	289
52	291	53	292	54	294	55	295
56	297	57	298	58	299	59	300
60	301	61	302	62	302	63	303
64	303	65	304	66	304	67	304
68	305	69	305	70	305	71	305
72	304	73	304	74	304	75	303
76	302	77	302	78	301	79	300
80	299	81	298	82	297	83	296
84	294	85	293	86	291	87	290
88	288	89	286	90	284	91	282
92	280	93	278	94	275	95	273
96	270	97	268	98	265	99	263
100	260	101	257	102	254	103	251
104	248	105	244	106	241	107	238
108	234	109	231	110	227	111	224
112	220	113	218	114	216	115	214
116	213	117	211	118	209	119	207
120	205	121	203	122	201	123	199
124	196	125	194	126	192	127	189
128	186	129	184	130	181	131	178
132	176	133	173	134	170	135	167

BEST CASE IRRADIATION DOSAGE AND I-V PARAMETERS AFTER 4 YEARS

EQUIVALENT FLUENCE FOR I_{SC} = 1.76E+14 1Mev e/cm^2
EQUIVALENT FLUENCE FOR V_{OC} AND P_{MAX} = 1.88E+14 1Mev e/cm^2
I_{SC} = 116.38mA + .100mA/°C (T-30°C)
V_{OC} = 567.16mV - 2.13mV/°C (T-30°C)
P_{MAX} = 49.16mW - .158mW/°C (T-30°C)
V_{MP} = 476.88mV - 1.87mV/°C (T-30°C)

WORST CASE IRRADIATION DOSAGE AND I-V PARAMETERS AFTER 4 YEARS

EQUIVALENT FLUENCE FOR I_{SC} = 3.96E+14 1Mev e/cm^2
EQUIVALENT FLUENCE FOR V_{OC} AND P_{MAX} = 4.28E+14 1Mev e/cm^2
I_{SC} = 101.47mA + .114mA/°C (T-30°C)
V_{OC} = 547.92mV - 2.20mV/°C (T-30°C)
P_{MAX} = 41.67mW - .147mW/°C (T-30°C)
V_{MP} = 462.80mV - 1.89mV/°C (T-30°C)

AVAILABLE SOLAR ARRAY POWER AFTER 4 YEARS

BETA (DEG)	POWER (WATTS)	BETA (DEG)	POWER (WATTS)	BETA (DEG)	POWER (WATTS)	BETA (DEG)	POWER (WATTS)
0	144	1	147	2	150	3	153
4	156	5	159	6	161	7	164
8	167	9	169	10	172	11	174
12	176	13	179	14	181	15	183
16	185	17	187	18	189	19	191
20	193	21	195	22	197	23	199
24	203	25	207	26	210	27	214
28	217	29	220	30	224	31	227
32	230	33	233	34	236	35	239
36	242	37	245	38	248	39	251
40	253	41	256	42	258	43	261
44	263	45	265	46	267	47	269
48	271	49	273	50	275	51	276
52	278	53	279	54	281	55	282
56	283	57	284	58	285	59	286
60	287	61	288	62	289	63	289
64	290	65	290	66	291	67	291
68	291	69	291	70	291	71	291
72	291	73	290	74	290	75	289
76	289	77	288	78	288	79	287
80	286	81	285	82	284	83	282
84	281	85	280	86	278	87	277
88	275	89	273	90	272	91	270
92	268	93	266	94	263	95	261
96	259	97	256	98	254	99	251
100	249	101	246	102	243	103	240
104	237	105	234	106	231	107	228
108	224	109	221	110	218	111	214
112	211	113	208	114	207	115	205
116	204	117	202	118	200	119	198
120	197	121	195	122	193	123	190
124	188	125	186	126	184	127	181
128	179	129	176	130	174	131	171
132	169	133	166	134	163	135	160

BEST CASE IRRADIATION DOSAGE AND I-V PARAMETERS AFTER 5 YEARS

EQUIVALENT FLUENCE FOR I_{SC} = 2.19E+14 1Mev e/cm^2

EQUIVALENT FLUENCE FOR V_{OC} AND P_{MAX} = 2.35E+14 1Mev e/cm^2

I_{SC} = 113.14mA + .105mA/°C (T-30°C)

V_{OC} = 563.02mV - 2.15mV/°C (T-30°C)

P_{MAX} = 47.48mW - .154mW/°C (T-30°C)

V_{MP} = 473.89mV - 1.87mV/°C (T-30°C)

WORST CASE IRRADIATION DOSAGE AND I-V PARAMETERS AFTER 5 YEARS

EQUIVALENT FLUENCE FOR I_{SC} = 4.95E+14 1Mev e/cm^2

EQUIVALENT FLUENCE FOR V_{OC} AND P_{MAX} = 5.35E+14 1Mev e/cm^2

I_{SC} = 97.71mA + .115mA/°C (T-30°C)

V_{OC} = 540.57mV - 2.21mV/°C (T-30°C)

P_{MAX} = 39.84mW - .145mW/°C (T-30°C)

V_{MP} = 457.32mV - 1.90mV/°C (T-30°C)

AVAILABLE SOLAR ARRAY POWER AFTER 5 YEARS

BETA (DEG)	POWER (WATTS)	BETA (DEG)	POWER (WATTS)	BETA (DEG)	POWER (WATTS)	BETA (DEG)	POWER (WATTS)
0	139	1	142	2	145	3	147
4	150	5	153	6	155	7	158
8	160	9	163	10	165	11	168
12	170	13	172	14	174	15	176
16	179	17	180	18	182	19	184
20	186	21	188	22	189	23	192
24	195	25	199	26	202	27	206
28	209	29	212	30	215	31	219
32	222	33	225	34	228	35	230
36	233	37	236	38	239	39	241
40	244	41	246	42	248	43	251
44	253	45	255	46	257	47	259
48	261	49	262	50	264	51	266
52	267	53	268	54	270	55	271
56	272	57	273	58	274	59	275
60	276	61	277	62	277	63	278
64	278	65	279	66	279	67	279
68	279	69	279	70	279	71	279
72	279	73	279	74	278	75	278
76	278	77	277	78	276	79	275
80	275	81	274	82	273	83	271
84	270	85	269	86	268	87	266
88	265	89	263	90	261	91	259
92	257	93	255	94	253	95	251
96	249	97	247	98	244	99	242
100	239	101	237	102	234	103	231
104	228	105	225	106	222	107	219
108	216	109	213	110	210	111	207
112	203	113	201	114	200	115	198
116	197	117	195	118	193	119	191
120	190	121	188	122	186	123	184
124	182	125	179	126	177	127	175
128	173	129	170	130	168	131	165
132	163	133	160	134	157	135	155

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BEST CASE IRRADIATION DOSAGE AND I-V PARAMETERS AF[illegible] YEARS

EQUIVALENT FLUENCE FOR I_{SC} = 2.63E+14 1Mev e/cm^2
EQUIVALENT FLUENCE FOR V_{OC} AND P_{MAX} = 2.82E+14 1Mev e/cm^2
I_{SC} = 110.35mA + .109mA/°C (T-30°C)
V_{OC} = 559.08mV - 2.17mV/°C (T-30°C)
P_{MAX} = 46.05mW - .151mW/°C (T-30°C)
V_{MP} = 471.01mV - 1.88mV/°C (T-30°C)

WORST CASE IRRADIATION DOSAGE AND I-V PARAMETERS AFTER 6 YEARS

EQUIVALENT FLUENCE FOR I_{SC} = 5.94E+14 1Mev e/cm^2
EQUIVALENT FLUENCE FOR V_{OC} AND P_{MAX} = 6.42E+14 1Mev e/cm^2
I_{SC} = 94.55mA + .117mA/°C (T-30°C)
V_{OC} = 533.81mV - 2.22mV/°C (T-30°C)
P_{MAX} = 38.31mW - .143mW/°C (T-30°C)
V_{MP} = 452.23mV - 1.91mV/°C (T-30°C)

AVAILABLE SOLAR ARRAY POWER AFTER 6 YEARS

BETA (DEG)	POWER (WATTS)	BETA (DEG)	POWER (WATTS)	BETA (DEG)	POWER (WATTS)	BETA (DEG)	POWER (WATTS)
0	135	1	137	2	140	3	143
4	145	5	148	6	150	7	153
8	155	9	158	10	160	11	162
12	164	13	167	14	169	15	171
16	173	17	175	18	177	19	178
20	180	21	182	22	183	23	186
24	189	25	192	26	196	27	199
28	202	29	205	30	208	31	211
32	214	33	217	34	220	35	223
36	225	37	228	38	230	39	233
40	235	41	238	42	240	43	242
44	244	45	246	46	248	47	250
48	251	49	253	50	255	51	256
52	258	53	259	54	260	55	261
56	262	57	263	58	264	59	265
60	266	61	267	62	267	63	268
64	268	65	268	66	269	67	269
68	269	69	269	70	269	71	269
72	269	73	269	74	268	75	268
76	267	77	267	78	266	79	266
80	265	81	264	82	263	83	262
84	261	85	259	86	258	87	257
88	255	89	254	90	252	91	250
92	249	93	247	94	245	95	243
96	241	97	238	98	236	99	234
100	231	101	229	102	226	103	223
104	221	105	218	106	215	107	212
108	209	109	206	110	203	111	200
112	197	113	194	114	193	115	192
116	190	117	189	118	187	119	185
120	184	121	182	122	180	123	178
124	176	125	174	126	172	127	170
128	167	129	165	130	163	131	160
132	158	133	155	134	153	135	150

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BEST CASE IRRADIATION DOSAGE AND I-V PARAMETERS AFTER 7 YEARS

EQUIVALENT FLUENCE FOR I_{SC} = 3.07E+14 1Mev e/cm^2

EQUIVALENT FLUENCE FOR V_{OC} AND P_{MAX} = 3.30E+14 1Mev e/cm^2

I_{SC} = 107.90mA + .113mA/°C (T-30°C)

V_{OC} = 555.31mV - 2.19mV/°C (T-30°)

P_{MAX} = 44.82mW - .149mW/°C (T-30°C)

V_{MP} = 468.25mV - 1.88mV/°C (T-30°C)

WORST CASE IRRADIATION DOSAGE AND I-V PARAMETERS AFTER 7 YEARS

EQUIVALENT FLUENCE FOR I_{SC} = 6.93E+14 1Mev e/cm^2

EQUIVALENT FLUENCE FOR V_{OC} AND P_{MAX} = 7.49E+14 1Mev e/cm^2

I_{SC} = 91.82mA + .118mA/°C (T-30°C)

V_{OC} = 527.54mV - 2.23mV/°C (T-30°C)

P_{MAX} = 37.01mW - .141mW/°C (T-30°C)

V_{MP} = 447.48mV - 1.92mV/°C (T-30°C)

AVAILABLE SOLAR ARRAY POWER AFTER 7 YEARS

BETA (DEG)	POWER (WATTS)	BETA (DEG)	POWER (WATTS)	BETA (DEG)	POWER (WATTS)	BETA (DEG)	POWER (WATTS)
0	131	1	133	2	136	3	138
4	141	5	144	6	146	7	148
8	151	9	153	10	155	11	158
12	160	13	162	14	164	15	166
16	168	17	170	18	171	19	173
20	175	21	176	22	178	23	180
24	183	25	187	26	190	27	193
28	196	29	199	30	202	31	205
32	208	33	210	34	213	35	216
36	218	37	221	38	223	39	226
40	228	41	230	42	232	43	234
44	236	45	238	46	240	47	242
48	243	49	245	50	246	51	248
52	249	53	250	54	251	55	252
56	253	57	254	58	255	59	256
60	257	61	257	62	258	63	258
64	259	65	259	66	259	67	260
68	260	69	260	70	260	71	260
72	260	73	259	74	259	75	259
76	258	77	258	78	257	79	256
80	256	81	255	82	254	83	253
84	252	85	251	86	250	87	248
88	247	89	245	90	244	91	242
92	241	93	239	94	237	95	235
96	233	97	231	98	229	99	226
100	224	101	222	102	219	103	217
104	214	105	211	106	208	107	206
108	203	109	200	110	197	111	194
112	191	113	189	114	187	115	186
116	185	117	183	118	182	119	180
120	178	121	177	122	175	123	173
124	171	125	169	126	167	127	165
128	163	129	160	130	158	131	156
132	153	133	151	134	148	135	146

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BEST CASE IRRADIATION DOSAGE AND I-V PARAMETERS AFTER 8 YEARS

EQUIVALENT FLUENCE FOR I_{SC} = 3.51E+14 1Mev e/cm^2
EQUIVALENT FLUENCE FOR V_{OC} AND P_{MAX} = 3.77E+14 1Mev e/cm^2
I_{SC} = 105.71mA + .114mA/°C (T-30°C)
V_{OC} = 551.70mV - 2.19mV/°C (T-30°C)
P_{MAX} = 43.73mW - .148mW/°C (T-30°C)
V_{MP} = 465.59mV - 1.89mV/°C (T-30°C)

WORST CASE IRRADIATION DOSAGE AND I-V PARAMETERS AFTER 8 YEARS

EQUIVALENT FLUENCE FOR I_{SC} = 7.92E+14 1Mev e/cm^2
EQUIVALENT FLUENCE FOR V_{OC} AND P_{MAX} = 8.56E+14 1Mev e/cm^2
I_{SC} = 89.43mA + .119mA/°C (T-30°C)
V_{OC} = 521.71mV - 2.24mV/°C (T-30°C)
P_{MAX} = 35.87mW - .140mW/°C (T-30°C)
V_{MP} = 443.03mV - 1.93mV/°C (T-30°C)

AVAILABLE SOLAR ARRAY POWER AFTER 8 YEARS

BETA (DEG)	POWER (WATTS)	BETA (DEG)	POWER (WATTS)	BETA (DEG)	POWER (WATTS)	BETA (DEG)	POWER (WATTS)
0	127	1	130	2	132	3	135
4	137	5	140	6	142	7	144
8	147	9	149	10	151	11	153
12	155	13	157	14	159	15	161
16	163	17	165	18	167	19	168
20	170	21	172	22	173	23	175
24	178	25	182	26	185	27	188
28	191	29	193	30	196	31	199
32	202	33	204	34	207	35	210
36	212	37	214	38	217	39	219
40	221	41	223	42	225	43	227
44	229	45	231	46	232	47	234
48	236	49	237	50	238	51	240
52	241	53	242	54	243	55	244
56	245	57	246	58	247	59	248
60	248	61	249	62	249	63	250
64	250	65	250	66	251	67	251
68	251	69	251	70	251	71	251
72	251	73	251	74	250	75	250
76	250	77	249	78	249	79	248
80	247	81	247	82	246	83	245
84	244	85	243	86	242	87	240
88	239	89	238	90	236	91	235
92	233	93	231	94	230	95	228
96	226	97	224	98	222	99	220
100	217	101	215	102	213	103	210
104	208	105	205	106	202	107	200
108	197	109	194	110	191	111	188
112	185	113	183	114	182	115	181
116	179	117	178	118	177	119	175
120	173	121	172	122	170	123	168
124	166	125	165	126	163	127	160
128	158	129	156	130	154	131	152
132	149	133	147	134	145	135	142

BEST CASE IRRADIATION DOSAGE AND I-V PARAMETERS AFTER 9 YEARS

EQUIVALENT FLUENCE FOR I_{SC} = 3.95E+14 1Mev e/cm^2

EQUIVALENT FLUENCE FOR V_{OC} AND P_{MAX} = 4.24E+14 1Mev e/cm^2

I_{SC} = 103.74mA + .114mA/°C (T-30°C)

V_{OC} = 548.24mV - 2.20mV/°C (T-30°C)

P_{MAX} = 42.76mW - .147mW/°C (T-30°C)

V_{MP} = 463.03mV - 1.89mV/°C (T-30°C)

WORST CASE IRRADIATION DOSAGE AND I-V PARAMETERS AFTER 9 YEARS

EQUIVALENT FLUENCE FOR I_{SC} = 8.91E+14 1Mev e/cm^2

EQUIVALENT FLUENCE FOR V_{OC} AND P_{MAX} = 9.63E+14 1Mev e/cm^2

I_{SC} = 87.29mA + .120mA/°C (T-30°C)

V_{OC} = 516.26mV - 2.25mV/°C (T-30°C)

P_{MAX} = 34.86mW - .138mW/°C (T-30°C)

V_{MP} = 438.85mV - 1.94mV/°C (T-30°C)

AVAILABLE SOLAR ARRAY POWER AFTER 9 YEARS

BETA (DEG)	POWER (WATTS)	BETA (DEG)	POWER (WATTS)	BETA (DEG)	POWER (WATTS)	BETA (DEG)	POWER (WATTS)
0	124	1	127	2	129	3	132
4	134	5	136	6	139	7	141
8	143	9	145	10	148	11	150
12	152	13	154	14	155	15	157
16	159	17	161	18	163	19	164
20	166	21	167	22	169	23	171
24	174	25	177	26	180	27	183
28	186	29	188	30	191	31	194
32	196	33	199	34	201	35	204
36	206	37	208	38	211	39	213
40	215	41	217	42	219	43	221
44	222	45	224	46	226	47	227
48	229	49	230	50	231	51	232
52	234	53	235	54	236	55	237
56	237	57	238	58	239	59	240
60	240	61	241	62	241	63	242
64	242	65	242	66	242	67	243
68	243	69	243	70	243	71	243
72	243	73	242	74	242	75	242
76	241	77	241	78	241	79	240
80	239	81	239	82	238	83	237
84	236	85	235	86	234	87	233
88	232	89	230	90	229	91	228
92	226	93	225	94	223	95	221
96	219	97	217	98	215	99	213
100	211	101	209	102	207	103	204
104	202	105	199	106	197	107	194
108	192	109	189	110	186	111	183
112	180	113	178	114	177	115	176
116	175	117	173	118	172	119	171
120	169	121	167	122	166	123	164
124	162	125	160	126	159	127	157
128	155	129	152	130	150	131	148
132	146	133	144	134	141	135	139

BEST CASE IRRADIATION DOSAGE AND I-V PARAMETERS AFTER 10 YEARS

EQUIVALENT FLUENCE FOR I_{SC} = 4.39E+14 1Mev e/cm^2
EQUIVALENT FLUENCE FOR V_{OC} AND P_{MAX} = 4.71E+14 1Mev e/cm^2
I_{SC} = 101.94mA + .115mA/°C (T-30°C)
V_{OC} = 544.91mV - 2.20mV/°C (T-30°C)
P_{MAX} = 41.87mW - .146mW/°C (T-30°C)
V_{MP} = 460.56mV - 1.90mV/°C (T-30°C)

WORST CASE IRRADIATION DOSAGE AND I-V PARAMETERS AFTER 10 YEARS

EQUIVALENT FLUENCE FOR I_{SC} = 9.90E+14 1Mev e/cm^2
EQUIVALENT FLUENCE FOR V_{OC} AND P_{MAX} = 1.07E+15 1Mev e/cm^2
I_{SC} = 85.36mA + .122mA/°C (T-30°C)
V_{OC} = 511.14mV - 2.26mV/°C (T-30°C)
P_{MAX} = 33.95mW - .137mW/°C (T-30°C)
V_{MP} = 434.90mV - 1.95mV/°C (T-30°C)

AVAILABLE SOLAR ARRAY POWER AFTER 10 YEARS

BETA (DEG)	POWER (WATTS)	BETA (DEG)	POWER (WATTS)	BETA (DEG)	POWER (WATTS)	BETA (DEG)	POWER (WATTS)
0	121	1	124	2	126	3	129
4	131	5	133	6	136	7	138
8	140	9	142	10	144	11	146
12	148	13	150	14	152	15	154
16	155	17	157	18	159	19	160
20	162	21	163	22	164	23	167
24	170	25	172	26	175	27	178
28	181	29	184	30	186	31	189
32	191	33	194	34	196	35	198
36	201	37	203	38	205	39	207
40	209	41	211	42	213	43	214
44	216	45	218	46	219	47	220
48	222	49	223	50	224	51	225
52	226	53	227	54	228	55	229
56	230	57	231	58	231	59	232
60	232	61	233	62	233	63	234
64	234	65	234	66	234	67	234
68	235	69	235	70	235	71	235
72	235	73	234	74	234	75	234
76	234	77	233	78	233	79	232
80	232	81	231	82	230	83	230
84	229	85	228	86	227	87	226
88	225	89	224	90	222	91	221
92	219	93	218	94	216	95	215
96	213	97	211	98	209	99	207
100	205	101	203	102	201	103	199
104	196	105	194	106	191	107	189
108	186	109	184	110	181	111	178
112	176	113	174	114	173	115	172
116	170	117	169	118	168	119	166
120	165	121	163	122	162	123	160
124	158	125	157	126	155	127	153
128	151	129	149	130	147	131	145
132	143	133	140	134	138	135	136