NASA TECHNICAL MEMORANDUM

NASA TM X-71713

NASA TM X-71713

(NASA-TM-X-71713) EFFECT OF ELECTRON IRRADIATION IN VACUUM ON FEP-A SILICON SOLAR CELL COVERS (NASA) 10 p HC $3.25 CSCL 18H

N75-23668

Unclas
G3/18 21830

EFFECT OF ELECTRON IRRADIATION IN VACUUM ON FEP-A SILICON SOLAR CELL COVERS

by Stanley J. Marsik and Jacob D. Broder
Lewis Research Center
Cleveland, Ohio 44135

TECHNICAL PAPER to be presented at
Eleventh Photovoltaic Specialists Conference
sponsored by the Institute of Electrical and
Electronics Engineers
Phoenix, Arizona, May 6-8, 1975

EFFECT OF ELECTRON IRRADIATION IN VACUUM ON FEP-A SILICON SOLAR CELL COVERS

by Stanley J. Marsik and Jacob D. Broder

National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio

E-8333

SUMMARY

Fluorinated ethylene-propylene-A (FEP-A) covers on silicon solar cells were irradiated with 1-MeV electrons, in vacuum, to an accumulated fluence of 2.5×10^{16} $\bar{e}/cm^2$ (6.75×10^{8} rads of absorbed dose for FEP-A material) equivalent to approximately 28 years in synchronous orbit. The effect of irradiation on the light transmittance of FEP-A was checked by measuring the short-circuit current of the cells after each dose increment, immediately after the irradiation and again after a minimum of 16 hours of elapsed time. The cells remained in vacuum for all these measurements. The results indicate no apparent overall loss in transmission due to irradiation of FEP-A. However, filter wheel measurements revealed a "darkening" of the FEP-A at the blue end of the spectrum, as evidenced by a small loss of current at the short wavelengths. The FEP-A solar cell cover was also tested for embrittlement. Although no delamination from the cell surface was observed while in vacuum, embrittlement of FEP-A occurred at this accumulated dose. The electron fluence at which the FEP-A cover embrittles and cracks when subjected to flexing tests was determined to be about 2.5×10^{15} electrons per square centimeter (6.75×10^{7} rads of absorbed dose).

INTRODUCTION

Fluorinated ethylene-propylene-A (FEP-A) has been proposed as a solar cell cover for use in outer space (Ref. (1)). The radiation damage properties of FEP-A must be determined before it can be considered for use as a solar cell cover material in a radiation environment. One of the most important properties to be evaluated is its light transmittance after radiation exposure. In general, organic materials tend to darken upon exposure to heavy doses of ionizing radiation. It is, therefore, important to determine whether FEP-A film darkens when it is exposed to radiation. Another important property to be examined after exposure to radiation is the brittleness and the strength of the material. This information is required of the FEP-A to be used for solar cell arrays which have to be folded or rolled up after exposure to ionizing radiation.

For the experiments described in this report, a thickness of 0.0127 centimeter was chosen because it is the closest commercially available thickness to the standard 0.015-centimeter (6-mil) cover glass. In previous investigations of this material the results were either obtained from testing in air after irradiation in vacuum (Refs. (1) and (2)) or not directly related to light transmittance (Refs. (3) and (4)). Most of the investigators concur that the absence of oxygen during the irradiation and the evaluation of the effects of irradiation in air are responsible for marked changes of the physical, electrical, and optical properties of FEP-A. To preclude any unknown effects that may occur if the simulated exposure is done in one environment and the measurements are made in another, the measurements should be performed in the same environment as the exposure. This report presents in-vacuum measurements of the effects of 1-million-electron-volt (1-MeV) electron irradiation on FEP-A light transmittance and observations of the physical integrity of FEP-A after irradiation. The 1-MeV electron fluence at which the brittleness of FEP-A begins in a completely encapsulated package was also determined and is included in this report.

The effects on the light transmittance were measured by comparing the radiation-induced loss in short-circuit current of the FEP-A covered cells with the corresponding loss experienced by an uncovered cell of the same type. During each measurement, the FEP-A was observed for possible loss in adherence to the cell surface. After the final irradiation the FEP-A was also tested for embrittlement and delamination in an argon atmosphere before exposure to air.

The electron fluence at which the brittleness begins was determined by flexing of the FEP-A encapsulated package in which FEP-A backed by FEP-20C and by Kapton was used as a hinge.

EXPERIMENTAL APPARATUS AND PROCEDURE

The tests for the FEP-A light transmittance and for its embrittlement, while in vacuum and subjected to ionizing radiation were conducted in a vacuum-tight chamber especially equipped with necessary ports for electron beam irradiation and solar simulator measurements and with electrical and thermocouple feed-throughs (Fig. 1). The chamber can be sealed while under high vacuum, decoupled from the beam transport pipe of the electron accelerator, and transported to the solar simulator facility for measurements of various parameters.

The vacuum leak rate of this apparatus is approximately 2×10^{-5} torr per minute. This allows almost 1 hour for handling in transport after decoupling from the vacuum system before the pressure within the chamber rises above the 10^{-4} torr range. It was only necessary to transport the chamber when performing light transmittance evaluation at the solar simulator facility. In this experiment the time in transport was less than 15 minutes, and the chamber was immediately connected to another vacuum system. The pressure inside the vessel during the irradiation was 1×10^{-6} torr. Thus, during this experiment the samples were not subjected to a pressure higher than 3×10^{-4} torr until after the final irradiation and measurements.

The quartz view ports were protected from radiation damage by 0.3-centimeter-thick aluminum shields fitted on the inside along the contour of the vessel. These shields, the specimen holder, and all other accessories involved in these experiments were mounted on a rotatable platform. The rotation of the platform was controlled electrically from the outside of the vacuum chamber.

The 1-MeV electron beam was provided by the Dynamitron potential-drop accelerator. The beam was focused to a vertical line of good uniform density and then moved to scan a 4- by 10-centimeter rectangular area uniformly. This allowed simultaneous irradiation of up to four 2-cell modules. The dose received by the cells was measured directly by a Faraday cup behind a 0.3-centimeter-diameter entrance aperture. The charge intercepted by the Faraday cup was measured by a current indicator and integrator. The rectangular area of the scanned beam was continuously monitored at its four corners by four independent probes.

Solar cell electric output measurements were made by using individually insulated contacts, which also served to hold the cells in place. No attempt was made to control the temperature of the specimen holder; however, this temperature and the temperature of the cells were monitored with thermocouples. The specimen holder arrangement is shown in Fig. 2.

For each set of electrical measurements the light-beam intensity was set for air-mass-zero conditions at the test plane by monitoring the short-circuit current of two reference cells positioned on the specimen holder outside the electron-beam target area and further protected by a movable shield during the irradiation. The reference current value for these cells was established before the experimental measurements by using Lewis filter wheel solar simulator currents (Ref. (5)). The reference cells were rechecked after the experiment to ensure that air-mass-zero conditions were maintained.

Procedure for the Light Transmittance Test

Prior to the experiment the following 10 ohm-centimeter, 0.0305-centimeter- (12-mil-) thick silicon solar cells with silicon monoxide (SiO) antireflection coating were selected at random: three 2- by 2-centimeter FEP-A covered cells prepared by a silane (Union Carbide A 1100) treatment method (unpublished work of J. D. Broder at the Lewis Research Center), one uncovered 2- by 2-centimeter cell to be used as a control cell for investigation of the FEP-A covers, and two 1- by 2-centimeter quartz glass-covered cells to be used as the reference cells. The initial measurements of short-circuit current (I_{sc}) for the 2- by 2-centimeter test cells were made under the filter wheel solar simulator. All these cells were also checked for their open-circuit voltage (V_{oc}). Upon installation inside the chamber the cells were again measured for I_{sc} under a Spectrolab X-25 solar simulator with the intensity adjusted to match the previously obtained I_{sc} for one of the 1- by 2-centimeter cells.

After the initial evacuation of the vessel the cells remained in vacuum throughout the test. The electron irradiation was stopped at accumulated fluences of 5×10^{14}, 1×10^{15}, 5×10^{15}, 6.5×10^{15}, 8×10^{15}, 1×10^{16}, 1.5×10^{16}, and 2.5×10^{16} electrons per square centimeter. Each time the cells were visually inspected through the window for physical damage and an average I_{sc} was determined from three readings under the Spectrolab X-25 solar simulator. The I_{sc} of the irradiated cells was measured within 15 minutes after the irradiation was stopped and then again after a minimum elapsed time of 16 hours to determine any annealing effect. After the accumulated fluence of 2.5×10^{16} electrons per square centimeter the vessel was prepared for opening in such a manner that the samples would not be exposed to air before probing to test the physical integrity of the FEP-A. The top cover of the vessel was sealed in a "dry bag," which was purged and then backfilled with argon gas. The pressure inside the vessel was slowly increased by allowing argon gas to leak in until a slight positive pressure was obtained. The FEP-A was then probed for brittleness and adherence to the cell in the dry bag filled with argon gas. Only after this test were the cells exposed to air and were V_{oc} and I_{sc} remeasured.

Procedure for the Brittleness Test

FEP-A covered 2-cell modules were prepared for this test. The test package consisted of: 0.0127 cm-thick FEP-A cover, two series-connected silicon solar cells, 0.00508 cm-thick FEP-20C, and 0.0025 cm-thick Kapton backing, laminated together. The modules were mounted on the same specimen holder as described above for the light transmittance test, and irradiated to various 1-MeV electron fluences in the above described vacuum chamber. Each module was flexed about the interconnect to an angle of about 12°. Breaks in the FEP-A cover on the module were observed using a four-power Micro Optical Pyrometer Telescope. Each module was first examined after two flexes. If no crack was observed, sample was flexed three more times and reexamined. The process was then continued in increments of five flexes until a hairline crack was observed. The flexing was done by a mechanical manipulator operated from the outside of the vacuum chamber. The highest 1-MeV electron fluence at which the FEP-A embrittles and separates into two pieces after a single flex was determined by using a "dummy" 2-cell module. This module was made by encapsulating 2- by 2-cm stainless steel, 0.0381 cm-thick, between 0.0127 and 0.00508 cm-thick FEP-A material.

RESULTS AND DISCUSSION

Measurements of V_{oc} of the three FEP-A covered cells and the uncovered control cell, prior to and after irradiation for the light transmittance test, are shown in Table I. The V_{oc} results before and after irradiation indicate that the samples were fairly uniform in characteristics and had resistivities very close to 10 ohm-centimeters.

Measurements of the Light Transmittance and Observations in Vacuum

The I_{sc} measurements of the four cells taken initially and at various 1-MeV electron irradiation levels were averaged and are shown in Table II. Each value listed is an average of three measurements. The temperature of the back of the cells during the irradiation stabilized at about 28° C for shorter dose increments and at about 30° C for longer irradiations.

The accumulated electron fluence of the FEP cover is more meaningful when expressed in terms of absorbed dose, in rads, where 1 rad = 100×10^{-7} joule per gram (100 ergs/g). This dose may be obtained to a reasonably accurate degree from the stopping power of silicon ((1.554 MeV)(cm^2)/g for 1-MeV electrons), determined by M. J. Berger and S. M. Seltzer (Ref. (6)), and by correcting the dose for the density of FEP (2.15 g/cm^3). Thus, for normal incidence of 1-MeV electrons, the absorbed dose in the FEP cover is 2.7×10^{-8} rad-square centimeter. The accumulated fluence of 2.5×10^{16} electrons per square centimeter represents an absorbed dose of 6.75×10^{8} rads.

An absorbed dose can be converted to an equivalent time in space by using Ref. (7). This reference presents tabulated information on equivalent 1-MeV electron fluence and absorbed dose due to the energy spectrum of trapped electrons in a synchronous equatorial orbit. The effect of protons is negligible in this orbit. From Table 6.8 of Ref. (7) the average absorbed dose at a depth of 0.0275 gram per square centimeter (0.0127-cm-thick FEP) is approximately 2.2×10^{7} rads per year for infinite backshielding. Since the cells used in this experiment would be backshielded in space with a combined thickness of FEP and Kapton of only 0.0183 gram per square centimeter, the front FEP cover would also receive a considerable dose through the back because of the omnidirectional nature of space radiation. This additional effect can be reasonably estimated from Table 6.21 of Ref. (7), which gives the absorbed dose in silicon under a shield in a synchronous, zero-inclination orbit. With a shield of FEP, Kapton, silver contact, and silicon having a combined thickness of 0.1306 gram per square centimeter, the absorbed dose under this shield is approximately 2×10^6 rads per year. Then the total dose in the FEP cover in synchronous orbit is about 2.4×10^7 rads per year. Thus, the absorbed dose in this experiment, corresponding to an accumulated 1-MeV electron fluence of 2.5×10^{16} electrons per square centimeter, would be equivalent to the dose absorbed in about 28 years in orbit.

For comparison purposes Fig. 3 shows data from this investigation superimposed on the normalized I_{sc} data from Ref. (7) for uncovered 7- to 13-ohm-centimeter N/P cells 0.0305 centimeter thick illuminated at 135 milliwatts per square centimeter. The spread of the experimental data points may be attributed mainly to measurement reproducibility errors. The uncertainty of the accumulated fluence, based on previous experience, is a maximum of 10 percent.

No I_{sc} changes were observed between measurements taken immediately after irradiation and those taken after a minimum time lapse of 16 hours. This agreement indicates no annealing in vacuum of either the FEP-A cover or the cells.

The FEP-A cover does not change its transparency, as indicated by total I_{sc} measured under the solar simulator, even at an accumulated 1-MeV electron fluence of 2.5×10^{16} electrons per square centimeter (6.75×10^9 rads of absorbed dose).

A photograph of the cells inside the vessel was obtained after the final irradiation increment, while they were still in vacuum, and it is shown in Fig. 2. No delamination of FEP-A or any other visible damage occurred to the cells. The cells were fully supported and subjected to no extraneous stresses, and they remained in this state until probed with a sharp object in an argon atmosphere. Probing revealed that the FEP-A film was brittle after the 1-MeV electron fluence of 2.5×10^{16} electrons per square centimeter. Attempts to lift and peel the FEP-A from the surface resulted only in removal of the cover immediately under the probe.

Measurements and Observations in Air Following the Light Transmittance Test

Upon removal of the cells from the argon atmosphere, I_{sc} and V_{oc} measurements were again made. The readings were in very close agreement with those obtained while the cells were still in vacuum. These measurements were repeated again after several hours. No changes were observed, which indicated that no annealing had taken place in several hours. Measurements made on the quartz glass window showed that no discoloration of the glass occurred during irradiation.

Immediately upon exposure to air, the FEP-A covered cells were measured in the filter wheel simulator. A filter-by-filter analysis of the currents indicated that "darkening" of the FEP-A in the violet to blue-violet region of the spectrum occurred. Changes in the selected wavelength interval short-circuit current of the cells are tabulated in Table III and are given as the percent of the initial current. For the FEP-A covered cells the value is the average of measurements of three cells. The uncovered cell value is that for one cell only. Normally the I_{sc} of a cell in the range from 0.4 to 0.5 µm does not change upon irradiation. This can be seen from the values of the uncovered cell for 0.4, 0.45, and 0.5 µm and for the FEP-A covered cells at 0.5 µm. The 103.4% value given for the uncovered cell current change at 0.4 µm should not be interpreted as a real increase in current. It is more probably due to the errors associated in determining a small change in current of low current values (approximately 0.1 mA). The decrease for the FEP-A covered cells is indicative of a loss in transparency of FEP-A in the 0.4 and 0.45 µm range. This is not unexpected, since most organic materials darken during irradiation.

For FEP-A this darkening affects the ultraviolet and blue portions of the spectrum. Because of the low sensitivity of the cell in this region of the spectrum, the increased short wavelength absorption has a minimal effect on the overall current output of the cell as measured under a Spectrolab X-25 solar simulator.

The current normally associated with the 0.4 µm region is 5 to 6 mA, and thus the loss of 10% shown in Table III would represent about 0.5 mA. An additional loss of 0.5 mA (6% of 8 mA) would be expected from the 0.45 µm spectral region. The total loss of about 1% is within the limits of error (±2%) of the filter wheel solar simulator system. Since the measurements were made immediately upon removal from the vacuum system, it is assumed that the darkening occurs during irradiation and exists in vacuum. It should be noted that the corresponding loss for high blue response cells would, of course, be greater than that observed in this experiment which employed normally diffused SiO-coated cells.

Within three weeks after exposure to air, other changes were noted in the FEP-A covered cells. One cover cracked and lifted from the cell surface separating at the SiO-to-cell interface. The color of the coatings on the remaining cells faded. Fig. 4 shows the condition of all four cells after 14 days in air. Both phenomena can be explained by the reactions that occur when FEP-A is irradiated and then exposed to oxygen. Electron irradiation causes scission of the long chain molecules with the release of some active form of fluorine (Ref. (8)). When the split chains are exposed to oxygen in the air, they react with the oxygen and further degradation occurs (Ref. (9)). It can be postulated that the active form of fluorine can react with the SiO coating to change its color and optical properties and/or release it from the cell surface. It is quite possible that in attacking the SiO coating the active fluorine species causes the release of some form of oxygen from the SiO coating, leading to damage of the FEP-A even in vacuum. A possible solution to this problem would be the use of nonoxide AR coating such as Si_3N_4 which has been shown to be compatible with FEP-A technology (Ref. (10)).

Determination of Electron Fluence at Which the Brittleness of FEP-A Begins

An absorbed dose at which the FEP-A used as a solar cell cover becomes too brittle to be bent through an angle of about 12°, was determined by flexing a module. The flexing angle between 10° and 12° would result if the solar array was rolled on an 8-inch diameter cylinder. A minimum of two flexes would be required for one operational cycle.

The samples were examined after 2, 5, 10 flexes, etc. Fig. 5 shows the range of flexes for several values of electron fluence, within which a hairline crack in the FEP-A occurred. The upper value indicates the number of flexes when a crack was first observed;

the lower value indicates the number of flexes at the prior examination. It should be noted that at the electron fluence of $1\times10^{15}\ \bar{e}/\mathrm{cm}^2$ no break was observed after 200 flexes and no attempt was made to establish the breaking point beyond this number of flexes. The curve through these data indicates the probable number of flexes needed to produce a hairline crack in the FEP-A cover, at various 1-MeV electron fluences. The critical electron fluence at which FEP-A sustains at least two flexes prior to cracking is about $2.5\times10^{15}\ \bar{e}/\mathrm{cm}^2$, which is equivalent to 6.75×10^7 rads of absorbed dose. At this critical fluence the Kapton-FEP-20C bond also separates. The data in Fig. 5 was obtained from 26 samples. The electron fluence at which the FEP-A embrittles and separates into two pieces, determined by using the "dummy" two-cell module, is between $2.8\times10^{15}\ \bar{e}/\mathrm{cm}^2$ and $3\times10^{15}\ \bar{e}/\mathrm{cm}^2$.

SUMMARY OF RESULTS

The following results were obtained from an investigation in which silicon solar cells covered with fluorinated ethylene-propylene-A (FEP-A) were irradiated in vacuum by 1-MeV electrons to a fluence of $2.5\times10^{16}\ \bar{e}/\mathrm{cm}^2$ (absorbed dose in the FEP-A cover of approximately 6.75×10^8 rads, equivalent to the dose absorbed in about 28 years in a synchronous equatorial orbit):

(a) The cells showed no delamination and no more loss of short-circuit current than that experienced by an uncovered cell. There was no apparent darkening of FEP-A, which would have reduced the short-circuit current more than the reduction caused by the irradiation of an uncovered cell.

(b) Measurements of the currents in air under the filter wheel simulator indicate a loss in transmission of the FEP-A in the violet to blue-violet region of the spectrum.

(c) At a 1-MeV electron fluence of $2.5\times10^{16}\ \bar{e}/\mathrm{cm}^2$ the FEP-A was very brittle. The critical fluence at which the FEP-A cover is too brittle to sustain at least two flexes comparable to those typical of a "roll-up" array was found to be $2.5\times10^{15}\ \bar{e}/\mathrm{cm}^2$ (6.75×10^7 rads of absorbed dose).

REFERENCES

1. A. F. Forestieri and J. D. Broder, "Improvement in Silicon Solar Cell Cover Glass Assembly and Packaging Using FEP Teflon" in IEEE 8th Photovoltaic Specialists Conf., Seattle, Wash., Aug. 4-6, 1970, pp. 179-182.

2. E. Anagnostou and A. E. Spakowski, "Transmission Effects on Plastic Films Irradiated with Ultraviolet Light, Electrons, and Protons," NASA TM X-1905, Oct. 1969.

3. C. E. Jolley and J. C. Reed, "The Effects of Space Environments on Insulation of Teflon TFE and FEP Resins," presented at Eleventh Annual Signal Cor Corps Wire and Cable Symposium, Asbury Park, N.J., Nov. 1962.

4. G. H. Bowers and E. R. Lovejoy, "Cross Linking of Teflon 100 FEP-Fluorocarbon Resin by Radiation," *I&EC Prod. Res. Develop.*, vol. 1, pp. 89-92, 1962.

5. J. Mandelkorn, J. D. Broder, and R. P. Ulman, "Filter Wheel Solar Simulator," NASA TN D-2562, Jan. 1965.

6. M. J. Berger and S. M. Seltzer, "Additional Stopping Power and Range Tables for Protons, Mesons, and Electrons," NASA SP-3036, 1966.

7. J. R. Carter, Jr. and H. Y. Tada, "Solar Cell Radiation Handbook," TRW-21945-6001-RU-00, TRW Systems Group, 1973. (Available as NASA CR-133738).

8. F. A. Bovey, *"The Effects of Ionizing Radiation on Natural and Synthetic High Polymers,"* New York: Interscience, 1958, pp. 151-155.

9. C. A. Sperati and H. W. Starkweather, Jr., "Fluorene-Containing Polymers - Polytetrafluoroethylene," *Advances in Polymer Science*, vol. 2, J. D. Ferry, C. G. Overberger, G. V. Shultz, A.J. Staverman, and H.A. Stuart, eds. Springer-Verlag, 1961, pp. 465-495.

10. J. D. Broder and G. A. Mazaris, "The Use of FEP Teflon in Solar Cell Cover Technology," presented at IEEE 10th Photovoltaic Specialists Conf., Palo Alto, Calif., Nov. 13-15, 1973.

TABLE I. - OPEN-CIRCUIT VOLTAGE OF FOUR SOLAR CELLS BEFORE AND AFTER IRRADIATION

Cell	Cover	Open-circuit voltage before irradiation, $V_{oc,0}$, V	Open-circuit voltage after irradiation, $V_{oc,1}$, V	Ratio of open-circuit voltage, $V_{oc,1}/V_{oc,0}$
1	FEP-A	0.55	0.47	0.85
2	FEP-A	.54	.46	.85
3	None	.54	.46	.85
4	FEP-A	.54	.47	.87

TABLE II. - SHORT-CIRCUIT CURRENT OF SOLAR CELLS BEFORE AND AFTER IRRADIATION

[Short-circuit current before irradiation, $I_{sc,0}$; short-circuit current after irradiation increment, $I_{sc,n}$.]

Cell	Cover	1-MeV electron fluence, electrons/cm^2																	
		0		5×10^{15}		1×10^{15}		5×10^{15}		6.5×10^{15}		8×10^{15}		1×10^{16}		1.5×10^{16}		2.5×10^{16}	
		Short-circuit current																	
		I_{sc}, mA	$I_{sc,n}/I_{sc,0}$	I_{sc}, mA	$I_{sc,n}/I_{sc,0}$	I_{sc}, mA	$I_{sc,n}/I_{sc,0}$	I_{sc}, mA	$I_{sc,n}/I_{sc,0}$	I_{sc}, mA	$I_{sc,n}/I_{sc,0}$	I_{sc}, mA	$I_{sc,n}/I_{sc,0}$	I_{sc}, mA	$I_{sc,n}/I_{sc,0}$	I_{sc}, mA	$I_{sc,n}/I_{sc,0}$	I_{sc}, mA	$I_{sc,n}/I_{sc,0}$
1	FEP-A	134	1.0	116	0.866	113	0.844	103	0.769	103	0.769	99	0.739	100	0.746	96.3	0.719	93.2	0.695
2	FEP-A	132	1.0	115	.871	112	.849	102	.773	101	.765	97	.735	97.7	.740	93.9	.711	90.4	.685
3	None	137	1.0	122	.890	117	.854	108	.789	107	.781	103	.751	104	.759	100	.730	95	.694
4	FEP-A	133	1.0	119	.895	114	.857	105	.790	104	.782	101	.760	102	.767	98.2	.739	92.8	.698

TABLE III. - PERCENT OF INITIAL I_{sc} AFTER IRRADIATION OF CONVENTIONAL SiO COATED AND FEP-A COVERED CELLS

Wavelength, λ, μm	Percent of initial I_{sc} after irradiation	
	FEP-A covered average of three cells, percent	Uncovered cell, percent
0.6 - 0.95	66.5	65.9
0.5	99.5	100.7
.45	93.9	99.1
.4	90.5	103.4

ORIGINAL PAGE IS
OF POOR QUALITY

PRECEDING PAGE BLANK NOT FILMED

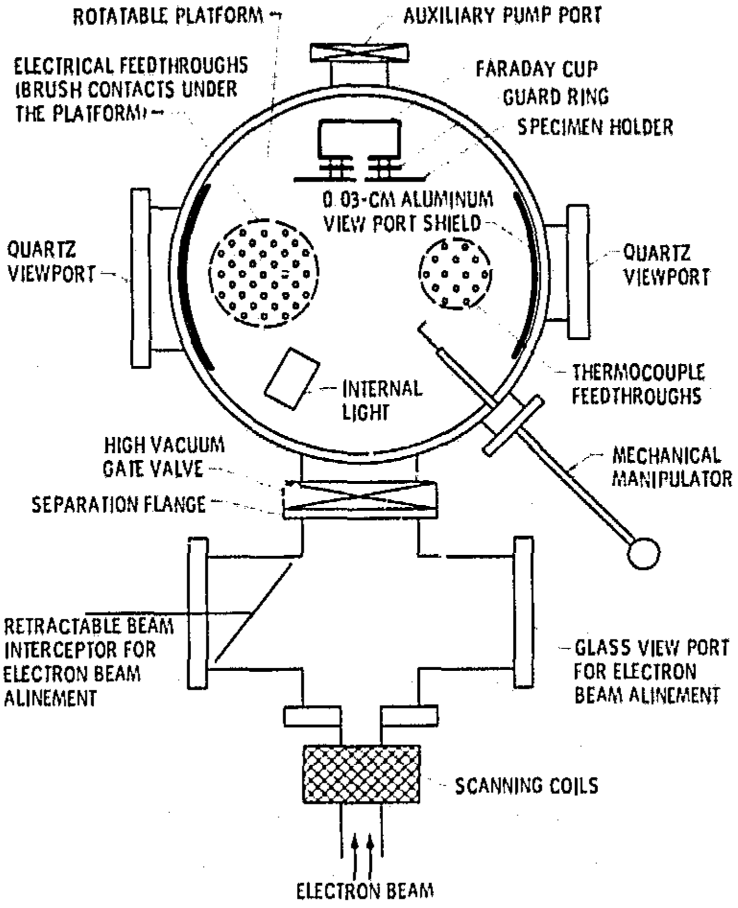

Figure 1. - Top view of experimental apparatus for irradiation.

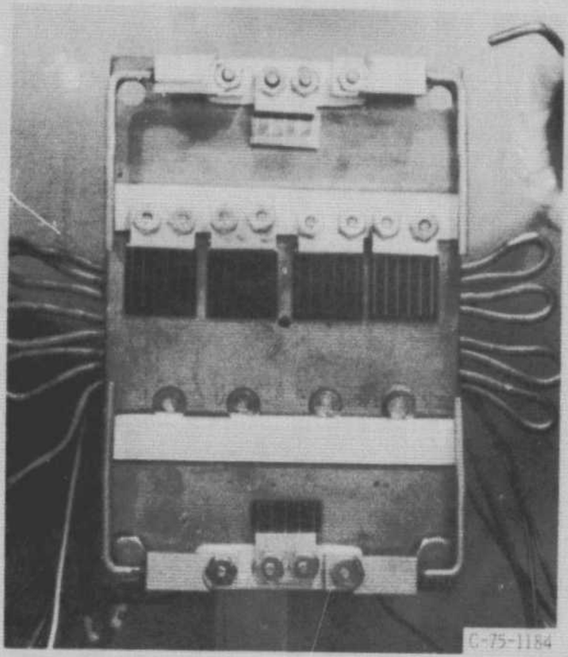

Figure 2. - Cells in vacuum after last irradiation. Test cells 2 by 2 centimeters; reference cells, 1 by 2 centimeters.

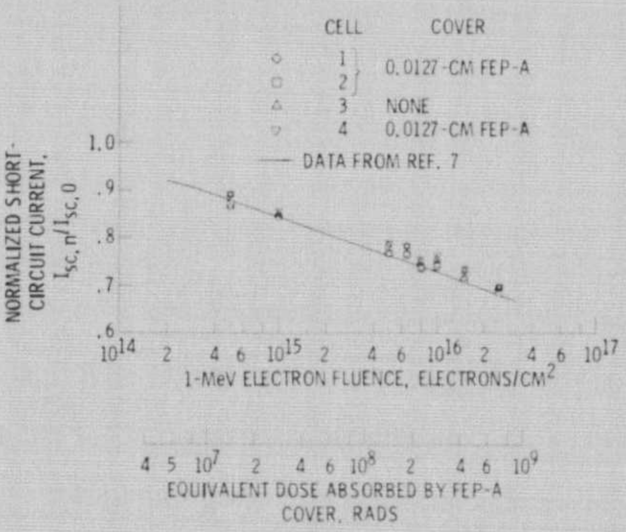

Figure 3. - Normalized short-circuit current as function of 1-MeV electron fluence. Total dose absorbed by FEP-A cover, 6.75×10^8 rads.

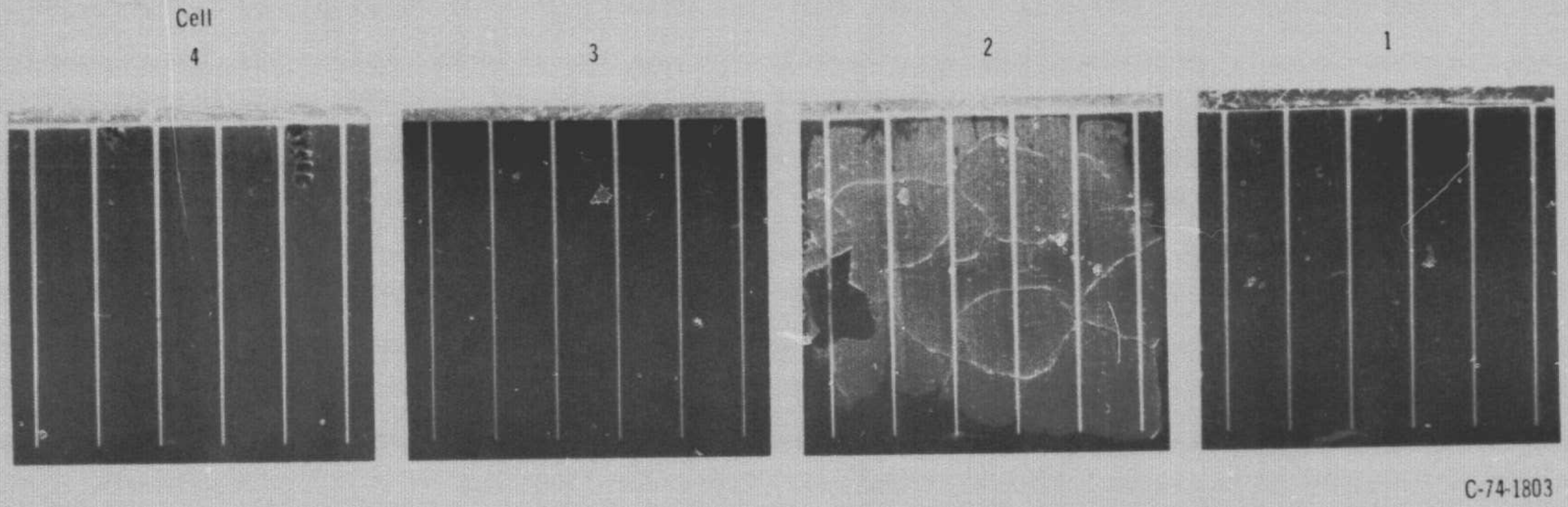

Figure 4. - Cells irradiated at 2.5×10^{16} electrons per square centimeter after 14 days in open air. Cell 2 shows cracked FEP-A and delamination, and cell 4 shows effects of probing.

E-8333

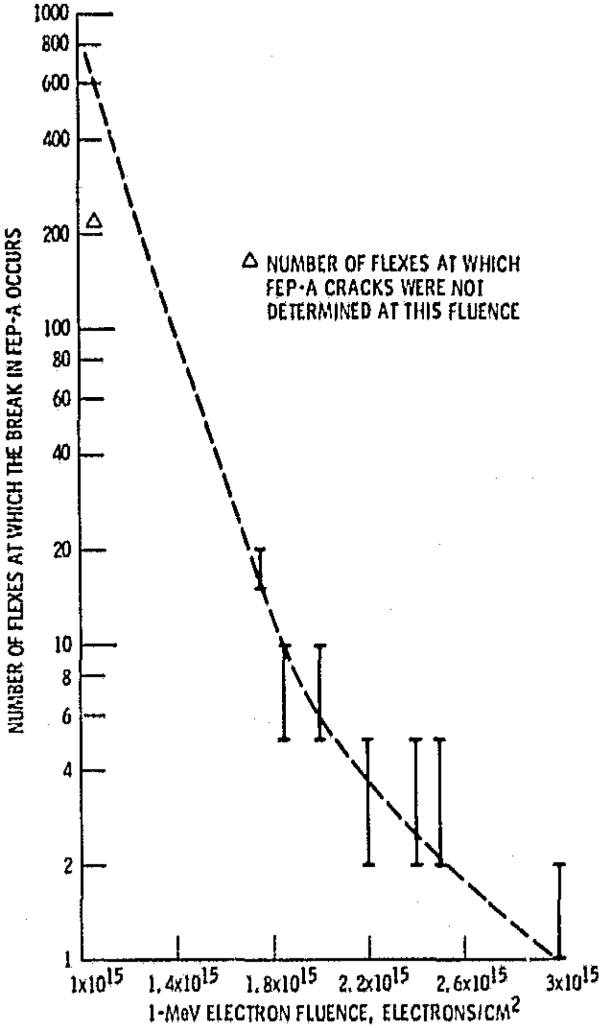

Figure 5. - Number of flexes sustained by FEP-A cover at various 1-MeV electron fluences.

NASA-Lewis