DEGRADATION ISSUES FOR FEP MULTILAYER INSULATION AND HANDRAIL PAINT ON HUBBLE SPACE TELESCOPE

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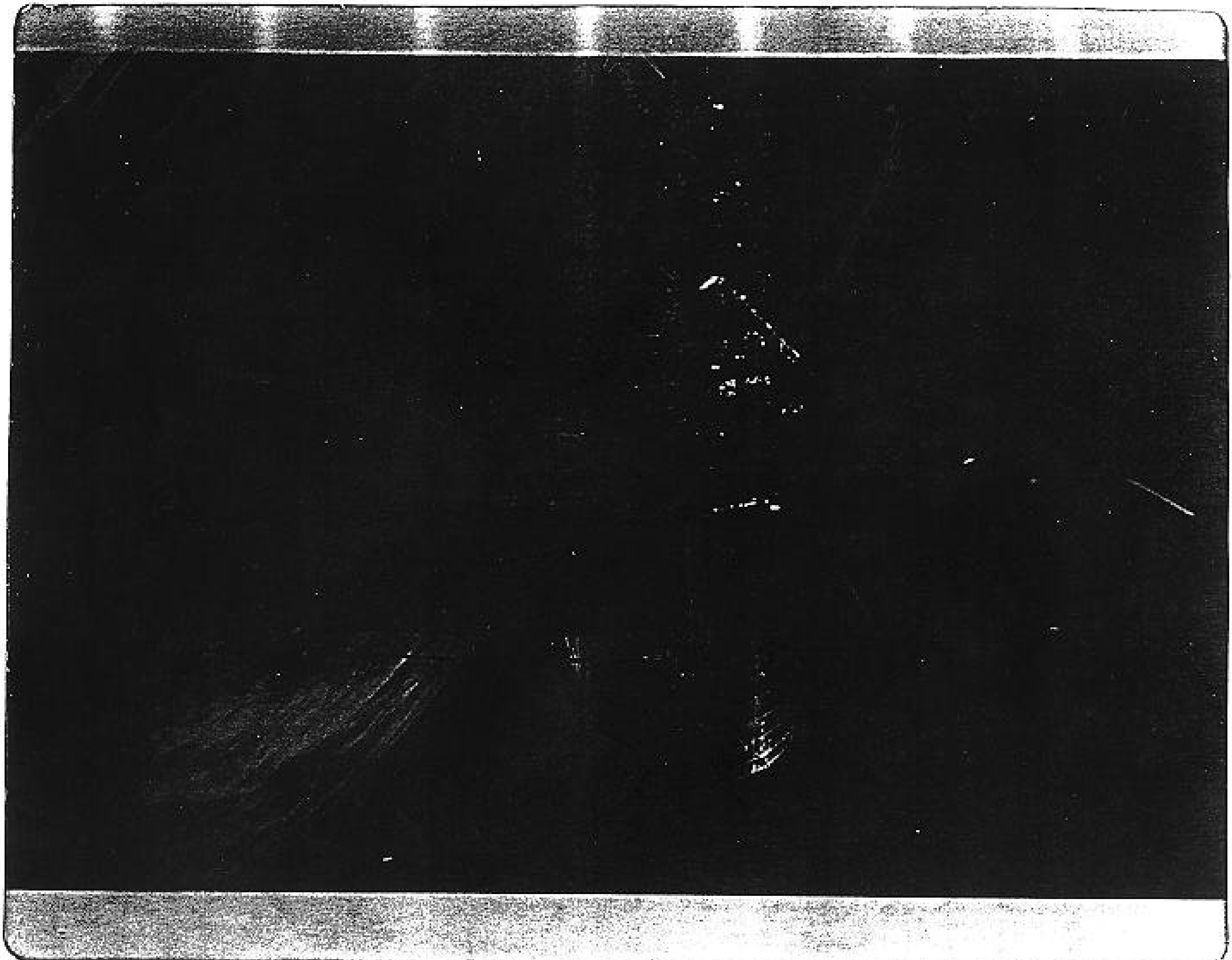
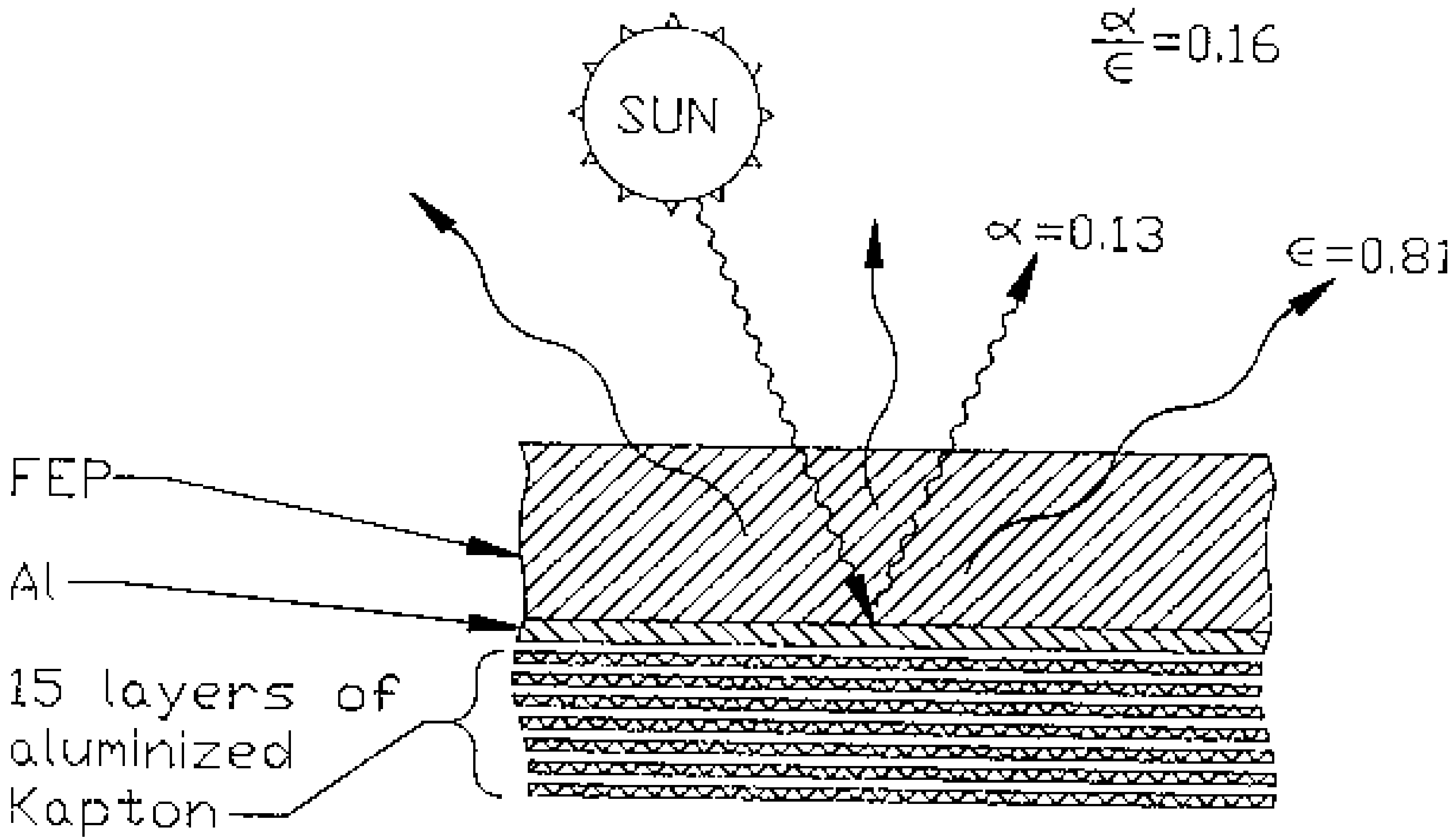
HUBBLE SPACE TELESCOPE

METALIZED FEP

MULTI-LAYER INSULATION

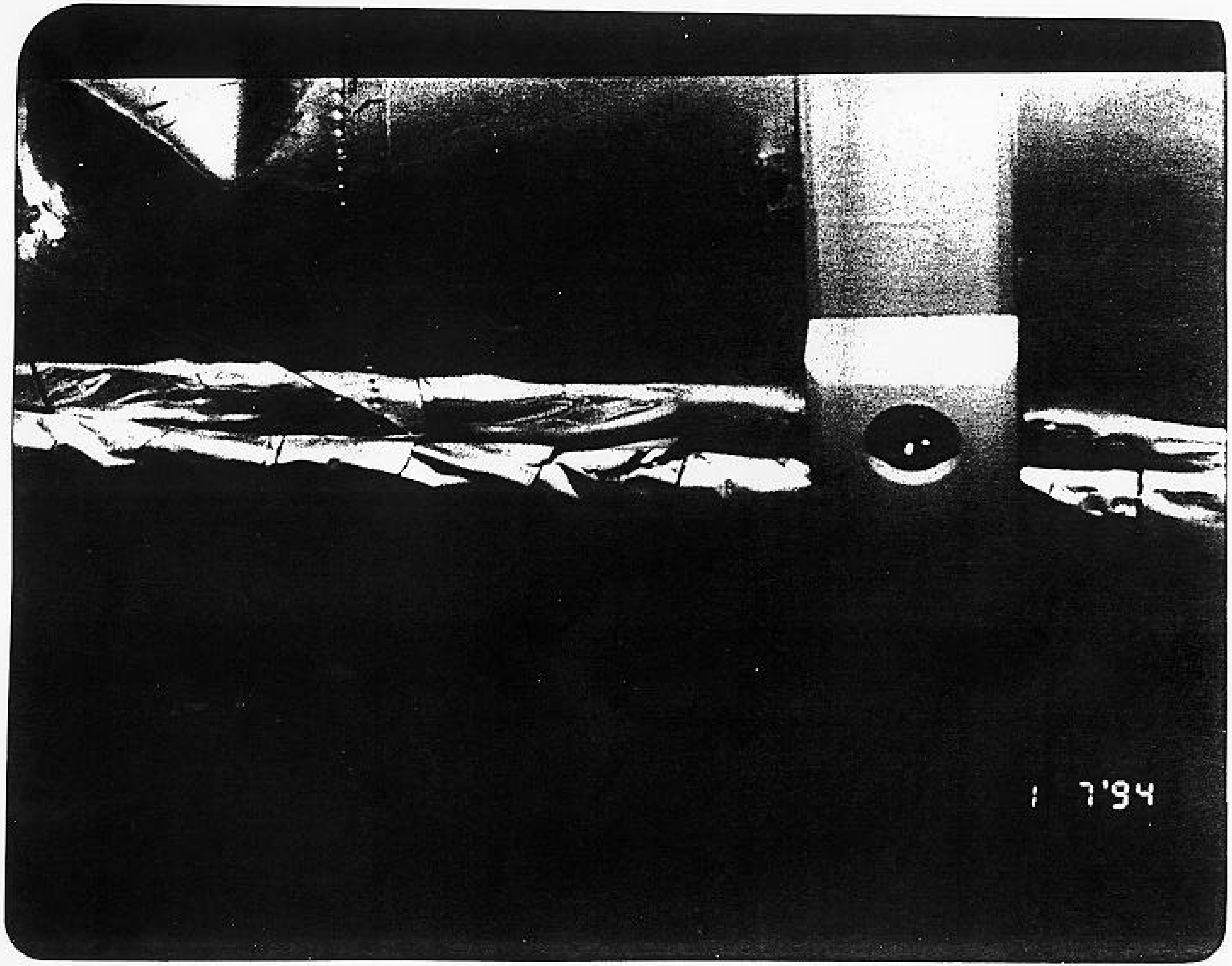


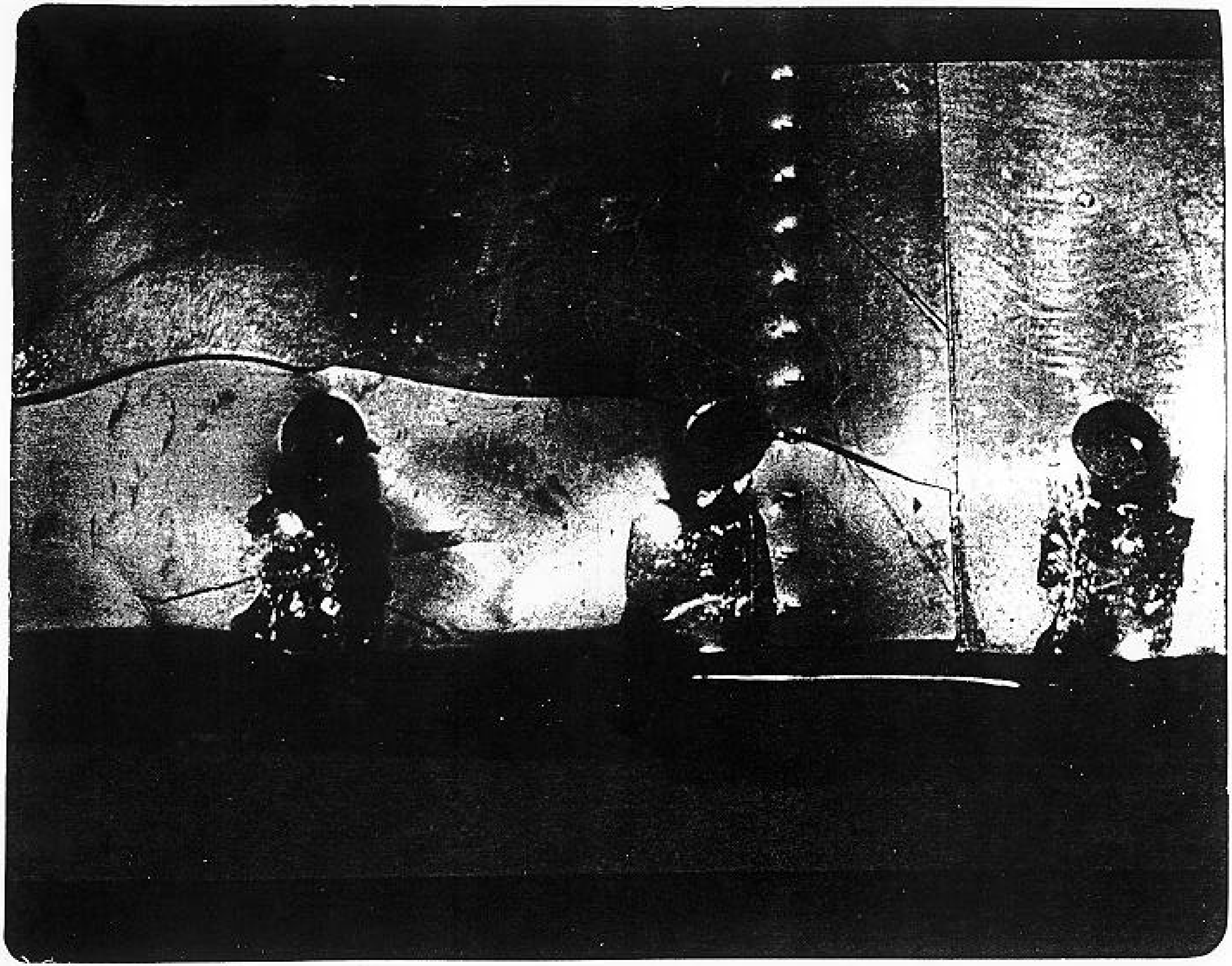


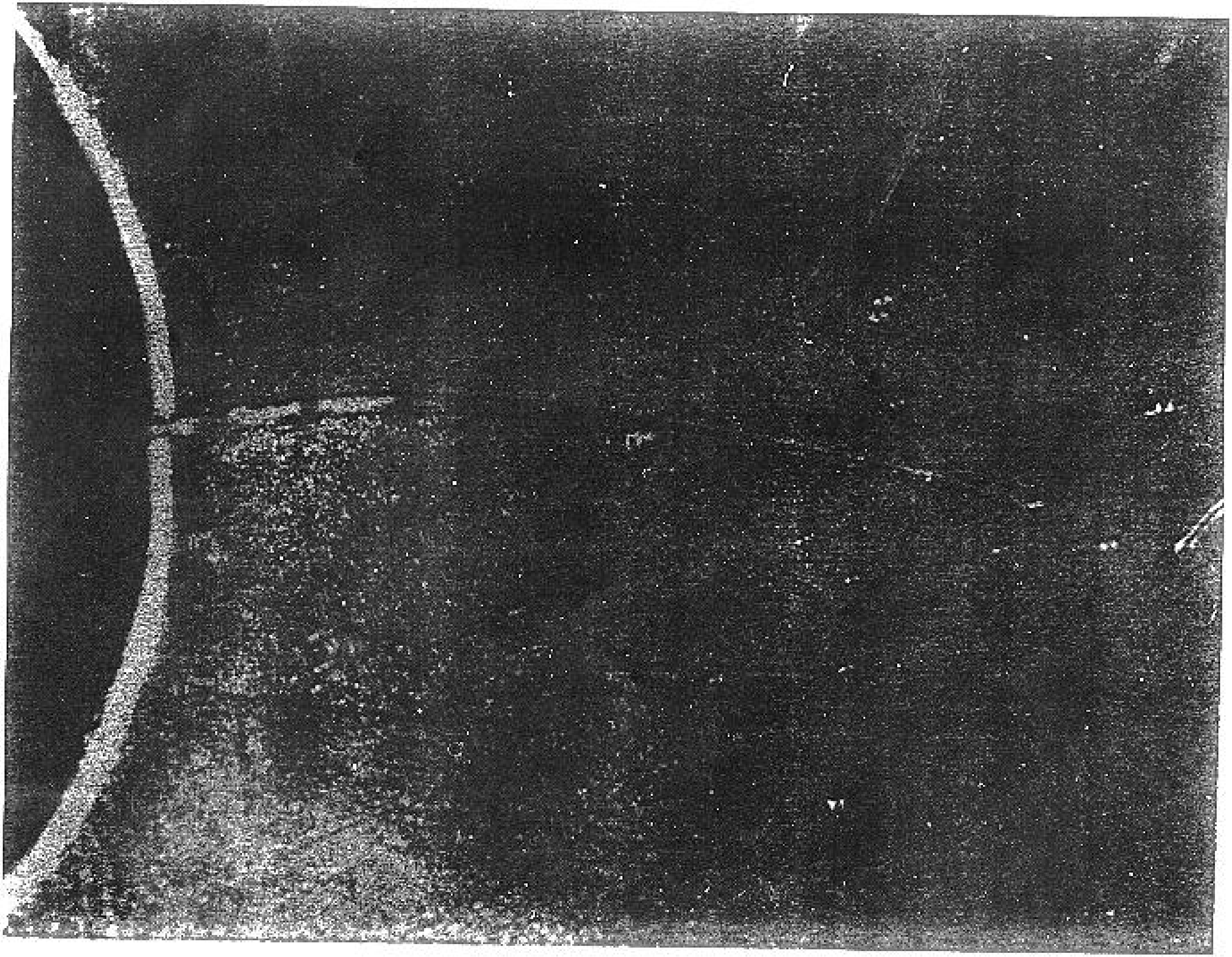
$\frac{\alpha}{\epsilon}=0.16$
SUN
$\alpha=0.13$
$\epsilon=0.81$
FEP
Al
15 layers of
aluminized
Kapton

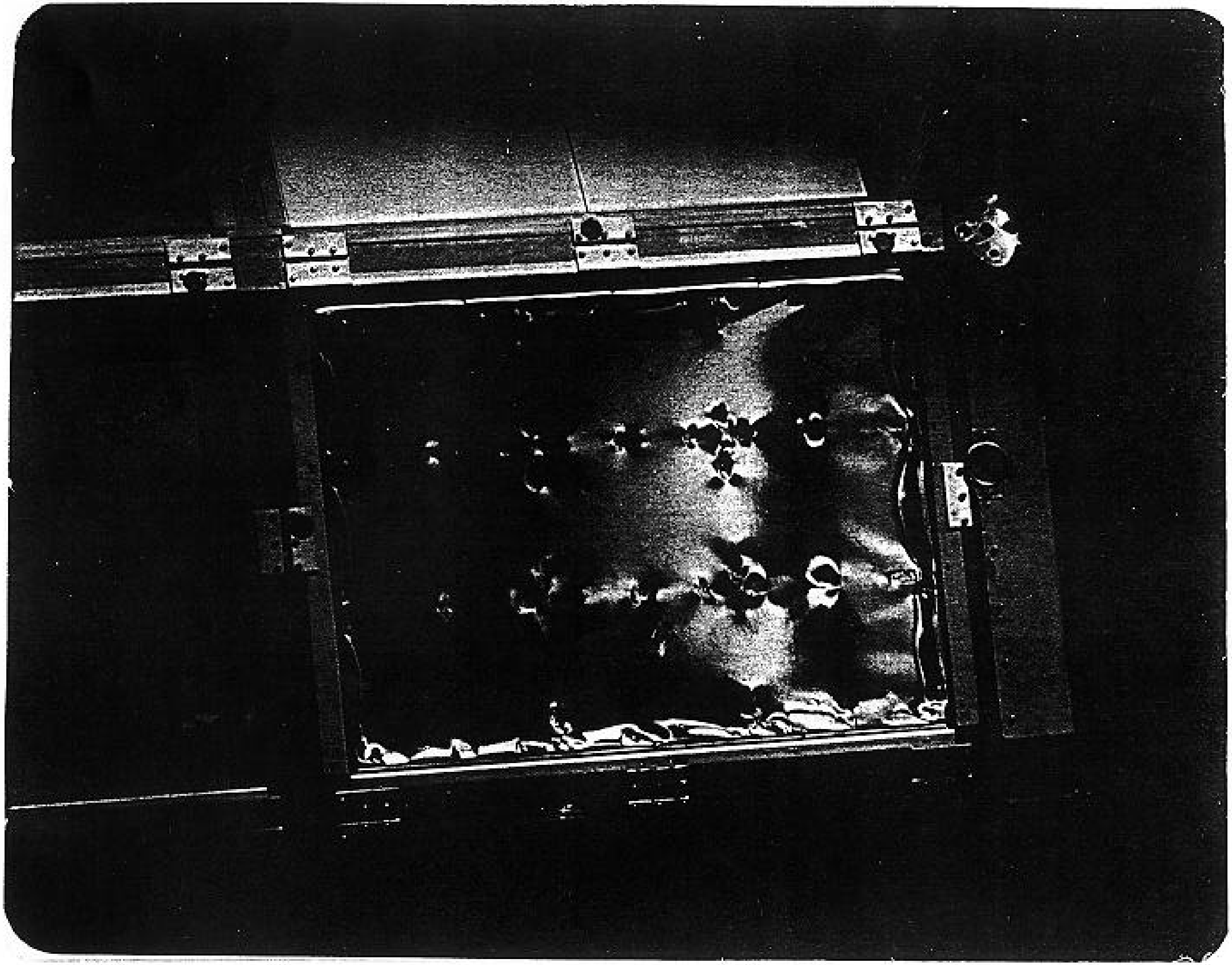
HUBBLE SPACE TELESCOPE

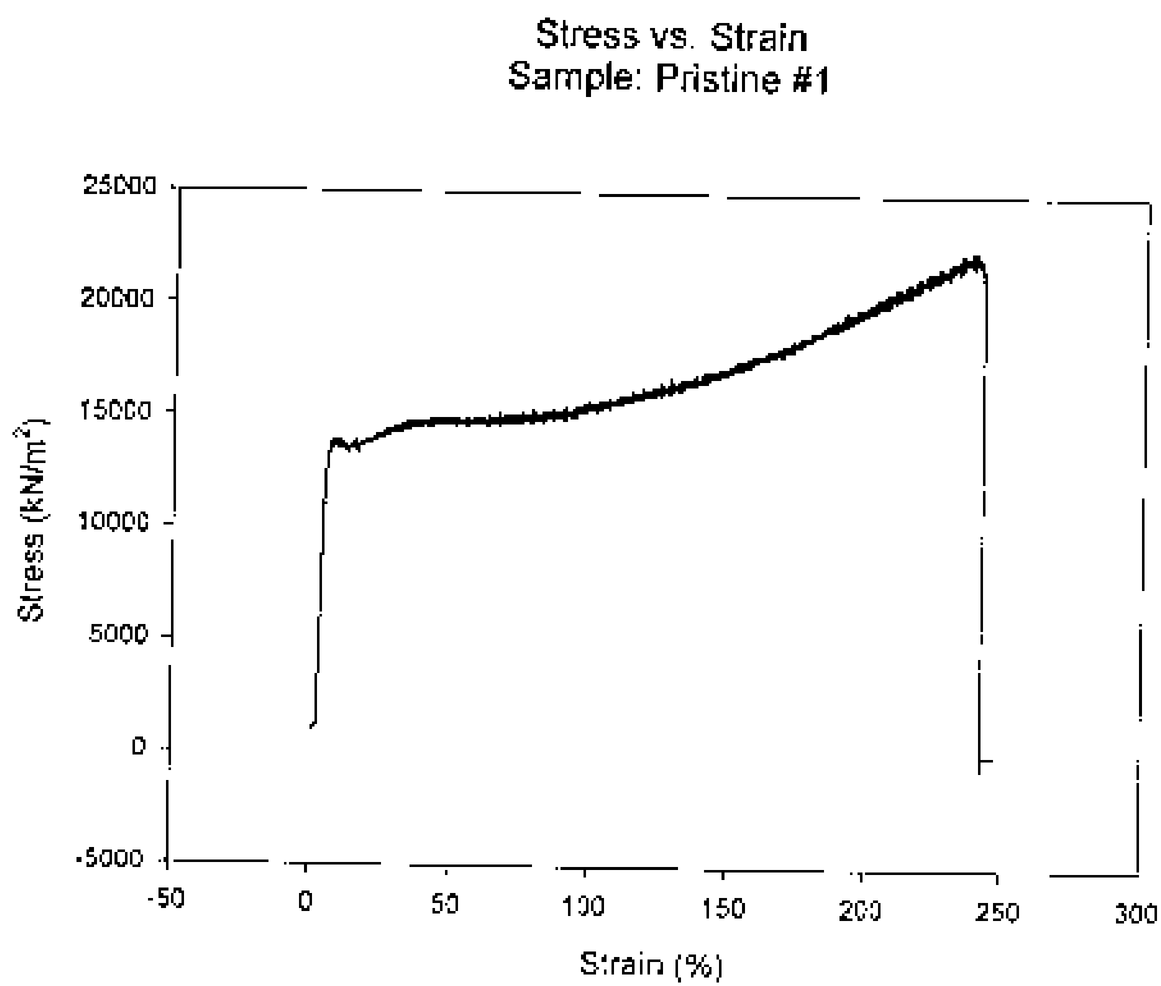
Event	Date	Thermal Cycles	Years in Space
Launch	April 25, 1990	0	0
Servicing Mission 1	December 1993	21,000	3.6
Servicing Mission 2	February 1997	40,000	6.8
Planned Servicing Mission 3	~~1999~~ 2000	57,466	9

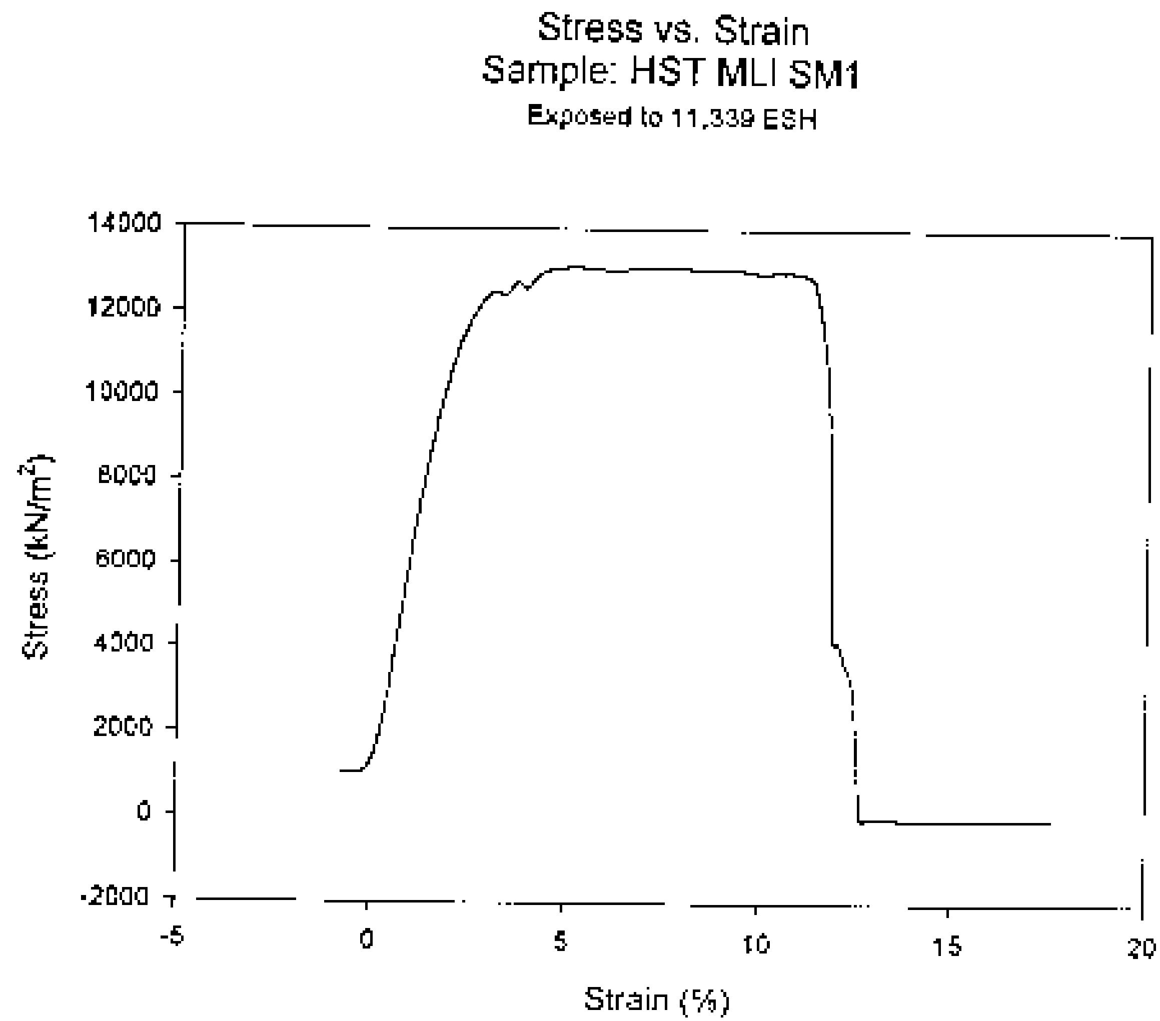

1 7'94



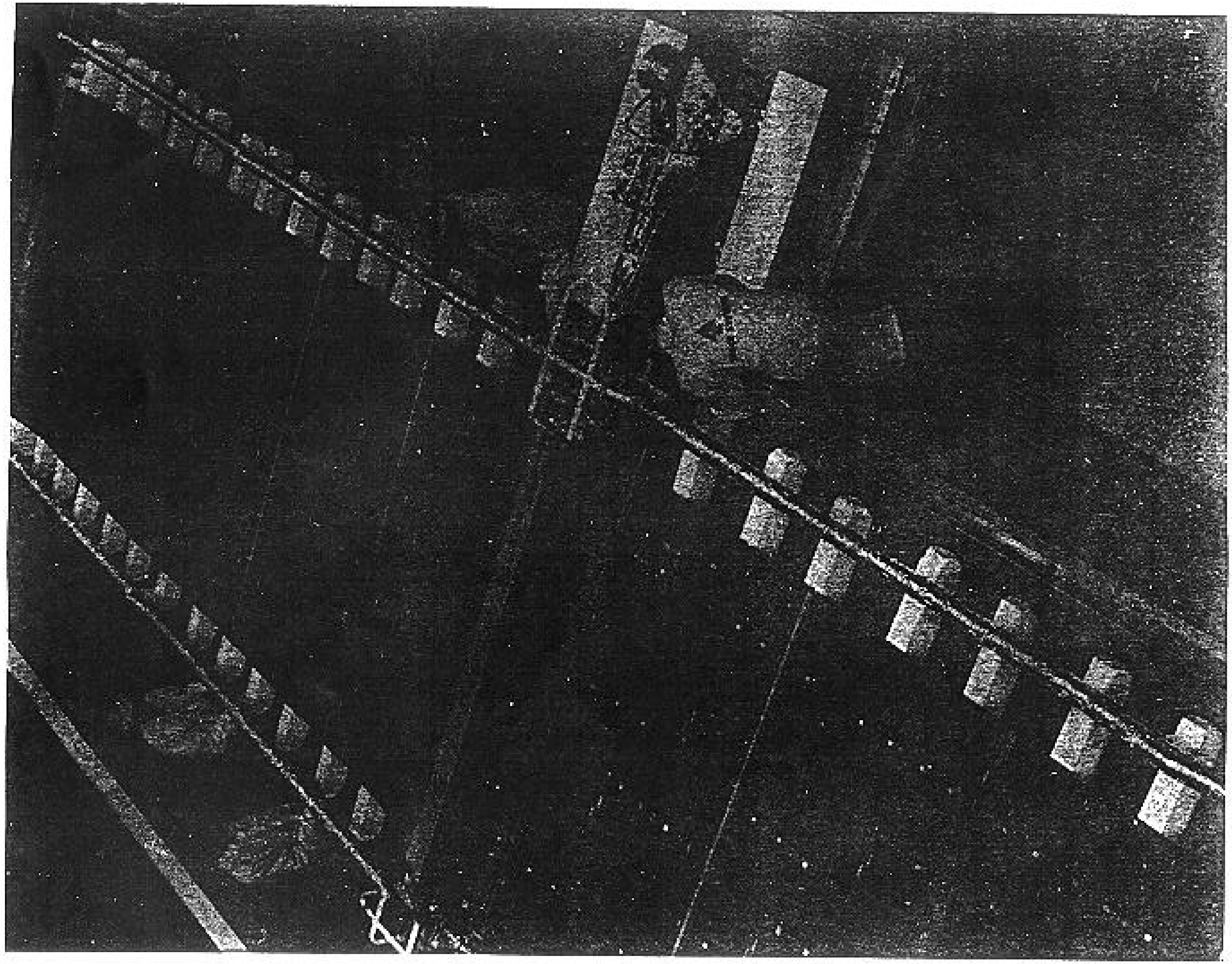


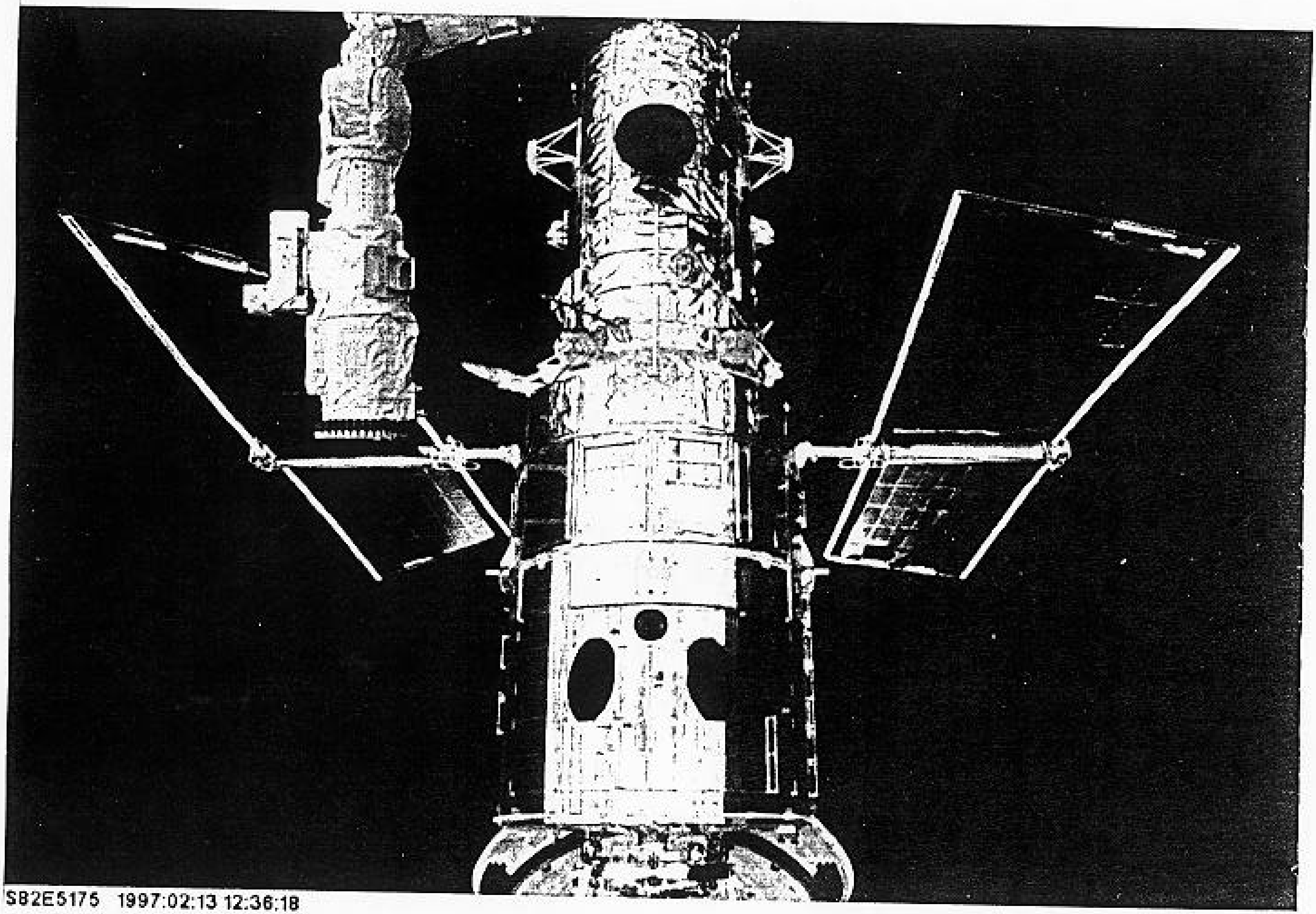



Stress vs. Strain
Sample: Pristine #1
Stress (kN/m²)
Strain (%)
25000
20000
15000
10000
5000
0
-5000
-50
0
50
100
150
200
250
300

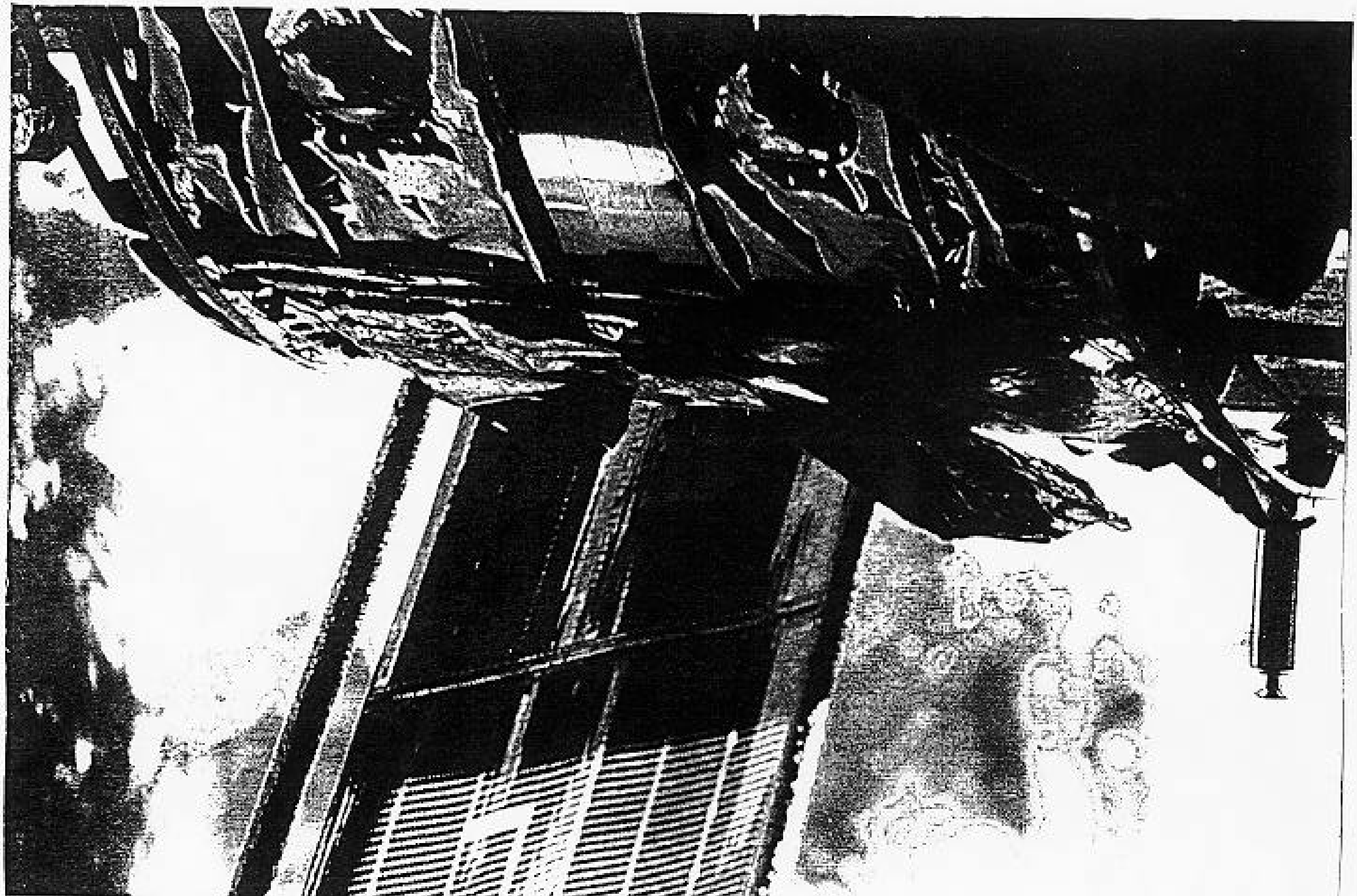


Stress vs. Strain
Sample: HST MLI SM1
Exposed to 11,339 ESH
14000
12000
10000
8000
6000
4000
2000
0
-2000
Stress (kN/m²)
-5
0
5
10
15
20
Strain (%)

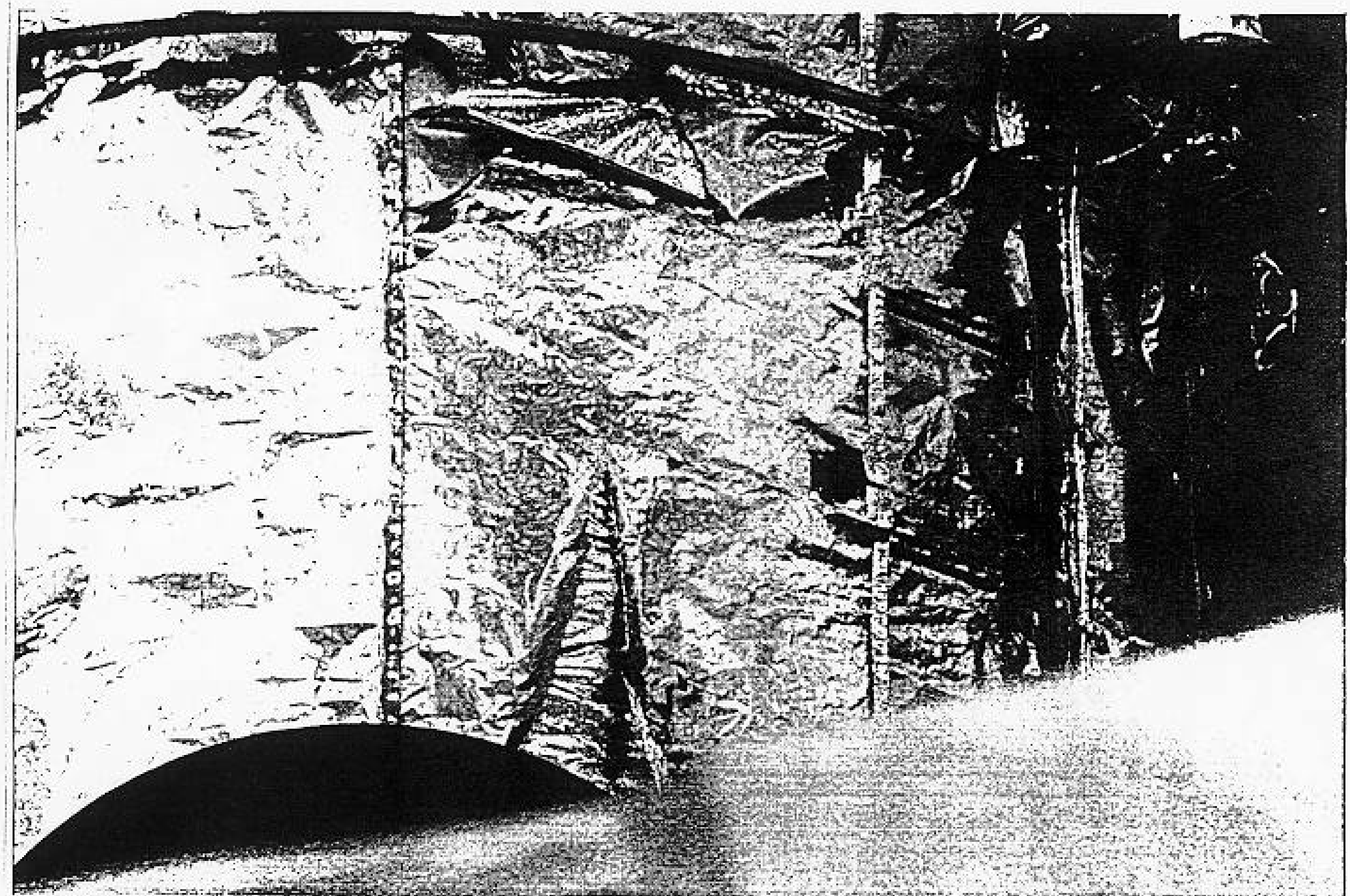




S82E5175 1997:02:13 12:36:18



S82E5368   1997:02:15 04:27:11



S82E5442 1997:02:15 11:17:06

HUBBLE SPACE TELESCOPE
METALIZED FEP DEGRADATION

SOLAR ABSORPTANCE INCREASE

CRACKING

REDUCTION IN ELONGATION

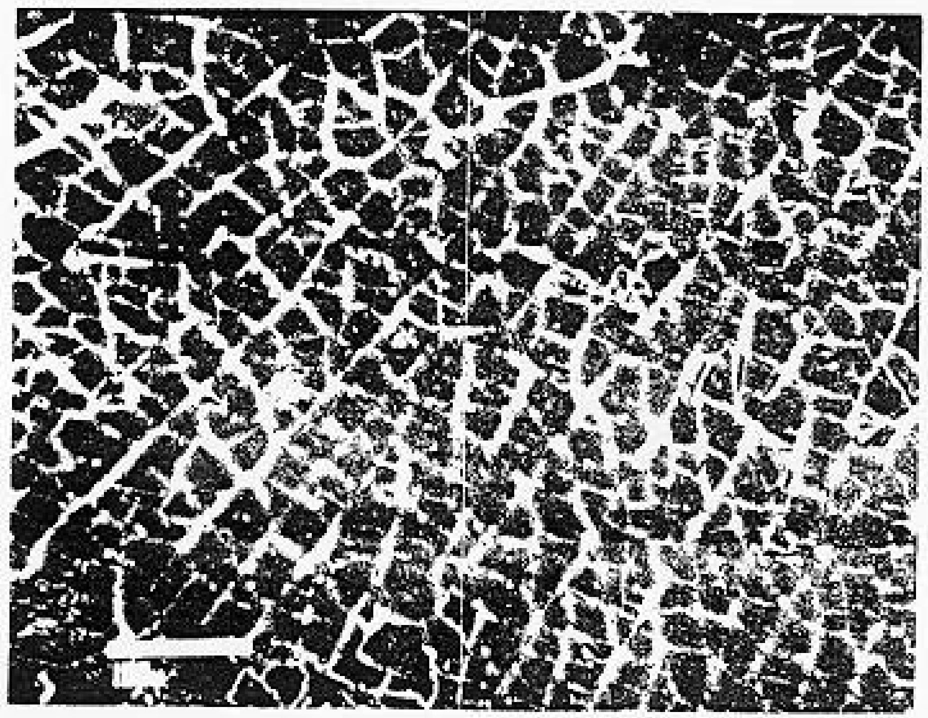
ENVIRONMENTAL INTERACTION CONSIDERATIONS

- ATOMIC OXYGEN
- MECHANICAL STRESS FROM CTE MISMATCH
- ULTRAVIOLET RADATION
- SOFT X-RAYS
- e^- & p^+
- THERMAL CYCLING

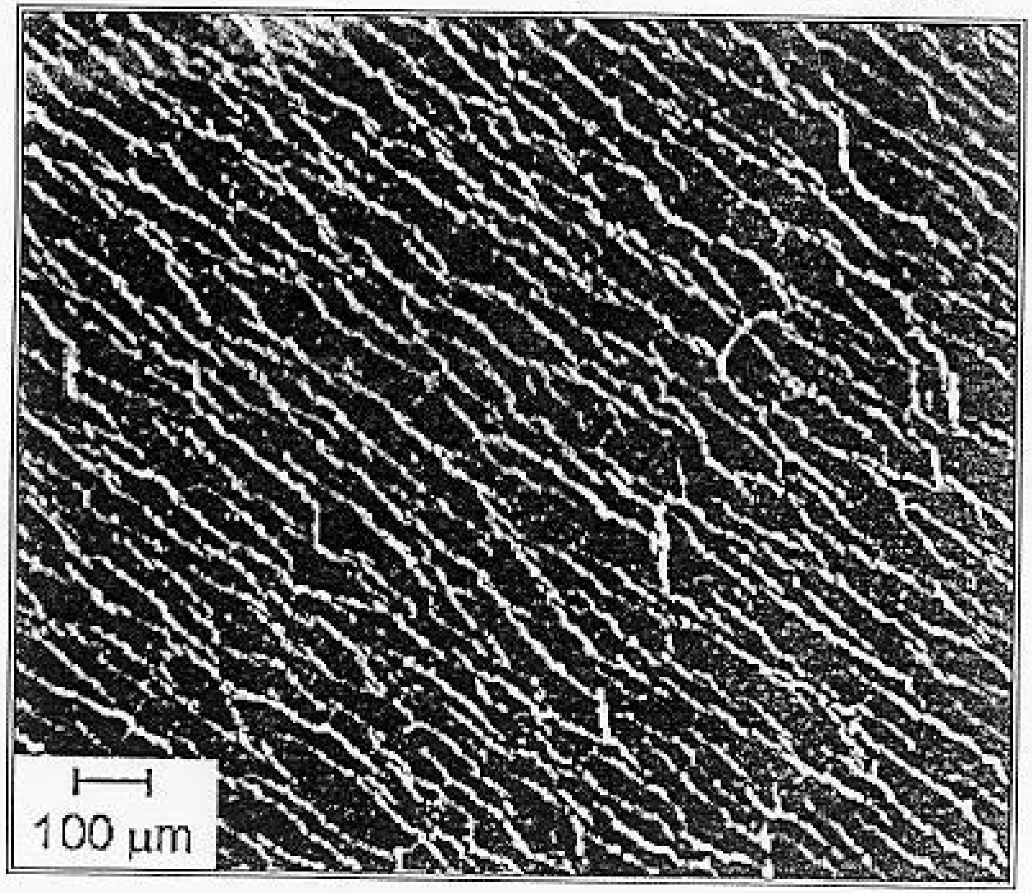
SM2 FLIGHT RETRIEVED HST MLI

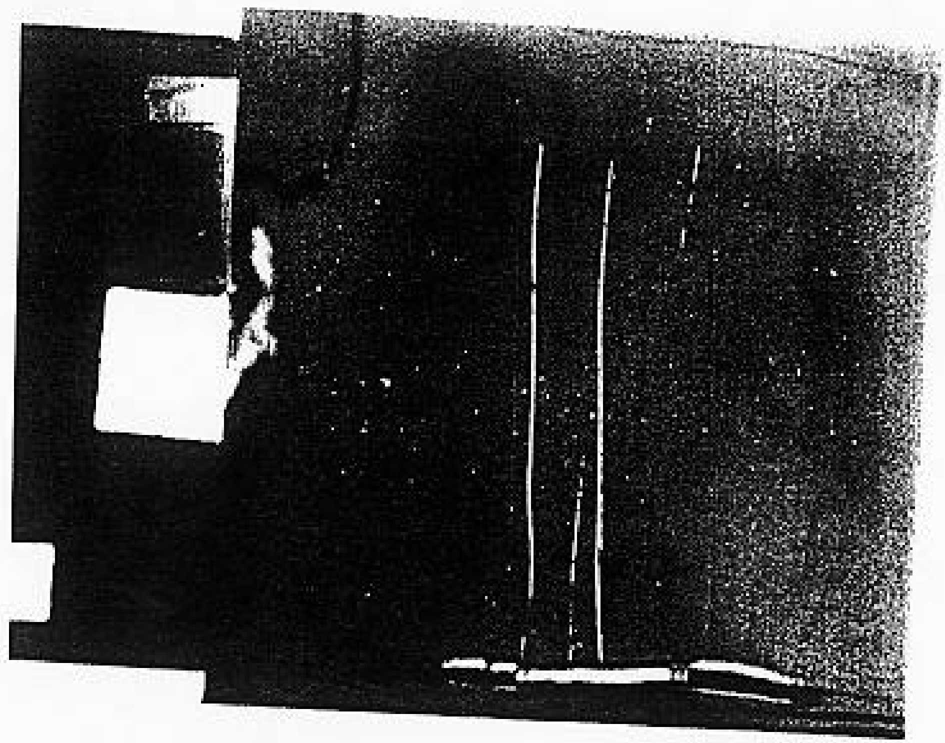
SEM OF Al SIDE OF ALUMINIZED FEP

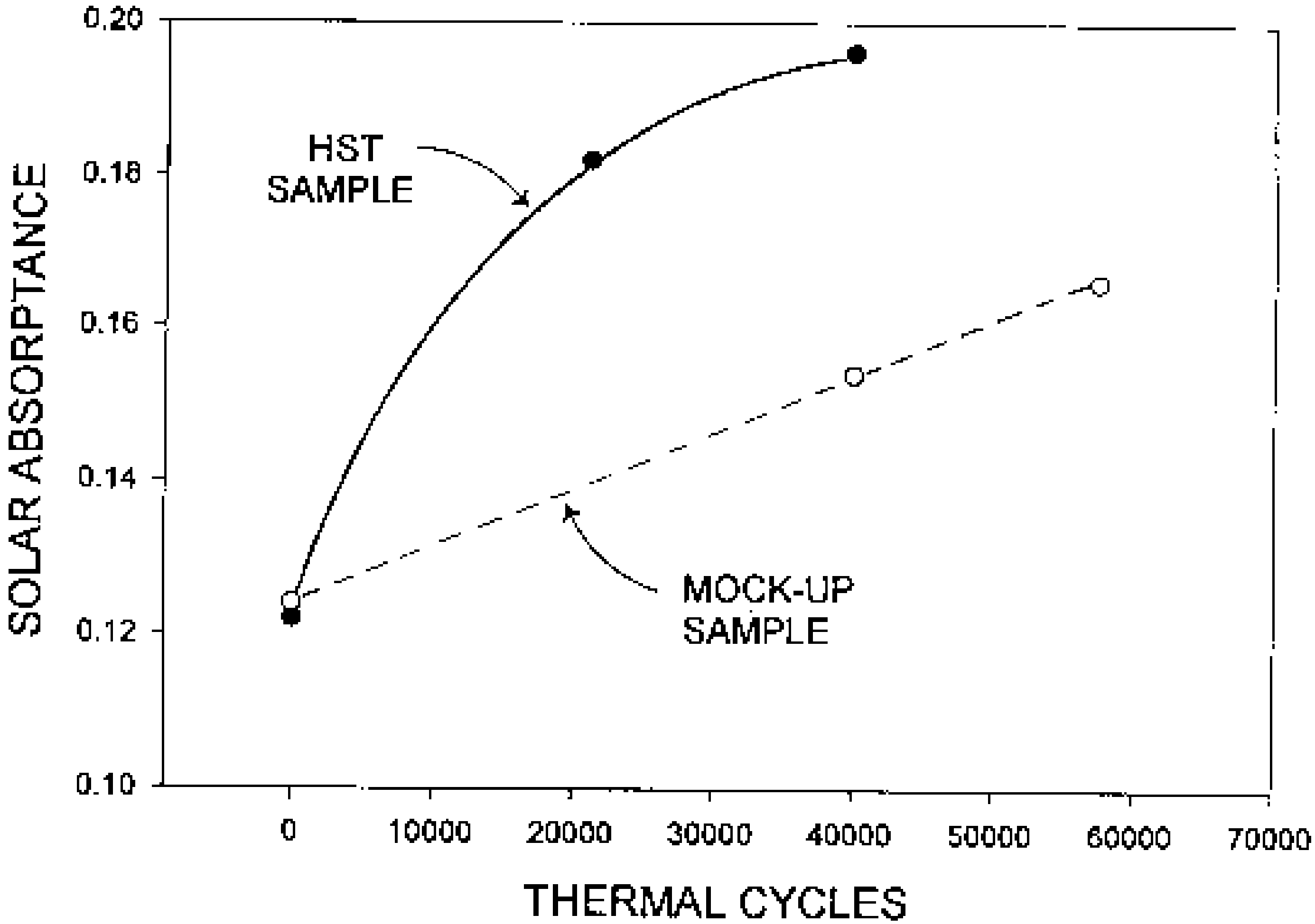
AFTER 40,000 THERMAL CYCLES



Optical Photograph Of
Aluminized FEP Teflon Ground Laboratory
Mock-up Sample After 40,000 Thermal Cycles







SOLAR ABSORPTANCE
0.20
0.18
0.16
0.14
0.12
0.10
HST
SAMPLE
MOCK-UP
SAMPLE
0
10000
20000
30000
40000
50000
60000
70000
THERMAL CYCLES

Environmental Fluences for Retrieved HST Thermal Control Materials

HST Sample	Thermal Cycling	Equivalent Sun Hours	X-ray Fluence (J/m^2)	Trapped Electron & Proton Fluence >40 keV ($\#/cm^2$)	Atomic Oxygen ($atoms/cm^2$)
SM1 MSS-A	19,500 cycles -100 to +50°C	16,670 (16% albedo)	.5-4Å: 11.6 1-8Å: 175	e^-: $1.39x10^{13}$ p^+: $7.96x10^{9}$	$7.8x10^{19}$
SM1 MSS-B/C		6,324 or 9,193 (72% or 33% alb.)	.5-4Å: 1.5 or 5.1 1-8Å: 22.1 or 77		$7.8x10^{19}$
SM1 MSS-D		11,339 (7% albedo)	.5-4Å: 8.7 1-8Å: 131.8		$1.56x10^{20}$
SM1 MSS-E/F		9,193 or 6,324 (33% or 72% alb.)	.5-4Å: 5.1 or 1.5 1-8Å: 77 or 22.1		$7.8x10^{19}$
SM1 MSS-G		4,477 100% albedo	0		$7.8x10^{19}$
SM1 SADA solar facing	19,500 cycles -100 to 100°C*	20,056* (2% albedo)	?	?	$2.16x10^{20}$*
SM2 LS (solar facing)	40,000 cycles -100 to +50°C (-100 to 200°C when curled)	33,638 direct (0% albedo)	.5-4Å: 16 1-8Å: 252.4	e^-: $2.13x10^{13}$ p^+: $1.83x10^{10}$	$1.64x10^{20}$
SM2 CVC	40,000 cycles -80 to -15°C	19,308 includes (33% albedo)	.5-4Å: 6.1 1-8Å: 96.9		

* Hubble Space Telescope Solar-Array Workshop Proceedings. ESA WPP-77

INFLUENCE OF X-RAY SOLAR FLARE RADIATION ON THE DEGRADATION OF FEP TEFLON IN SPACE

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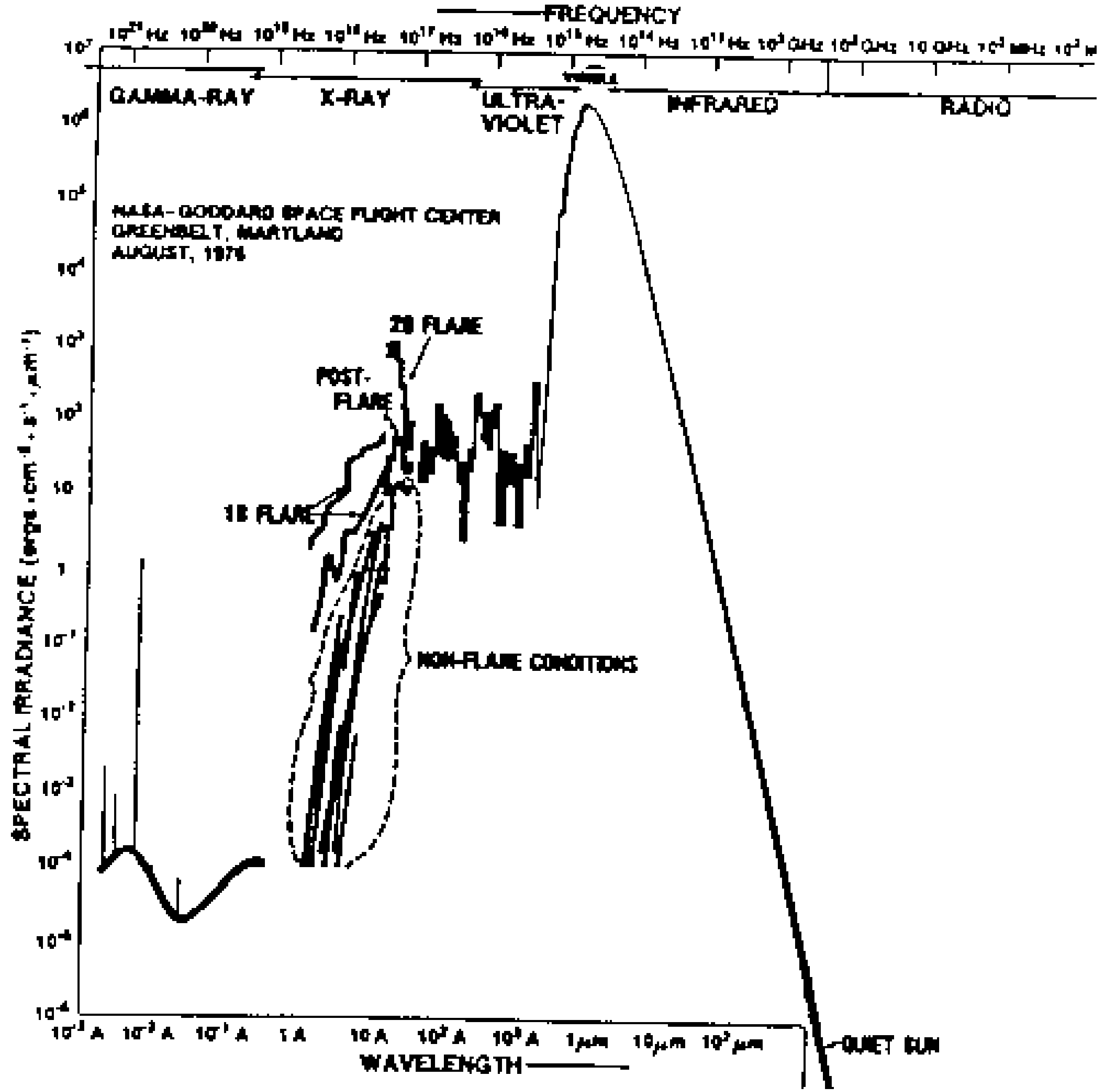
ABSTRACT

FEP Teflon material is widely used in space applications. The post flight investigations performed on FEP Teflon after sixty-nine months of space exposure on the LDEF spacecraft and after forty-three months on board the Hubble Space Telescope have shown large variations in the mechanical and chemical properties between these two missions and between different positions on LDEF. It is proposed that X-Ray radiation due to flares is playing a major role in these variations.



FREQUENCY
GAMMA-RAY
X-RAY
ULTRA-VIOLET
INFRARED
RADIO
NASA-GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND
AUGUST, 1976
2B FLARE
POST-FLARE
1B FLARE
NON-FLARE CONDITIONS
QUIET SUN
SPECTRAL IRRADIANCE
WAVELENGTH

SYNCHROTRON SOFT X-RAY TESTING

ENERGY, ev	WAVELENGTH, nm
69	17.97
290	4.27
510	2.43
700	1.77
1256	0.99
1489	0.83
1900	0.65

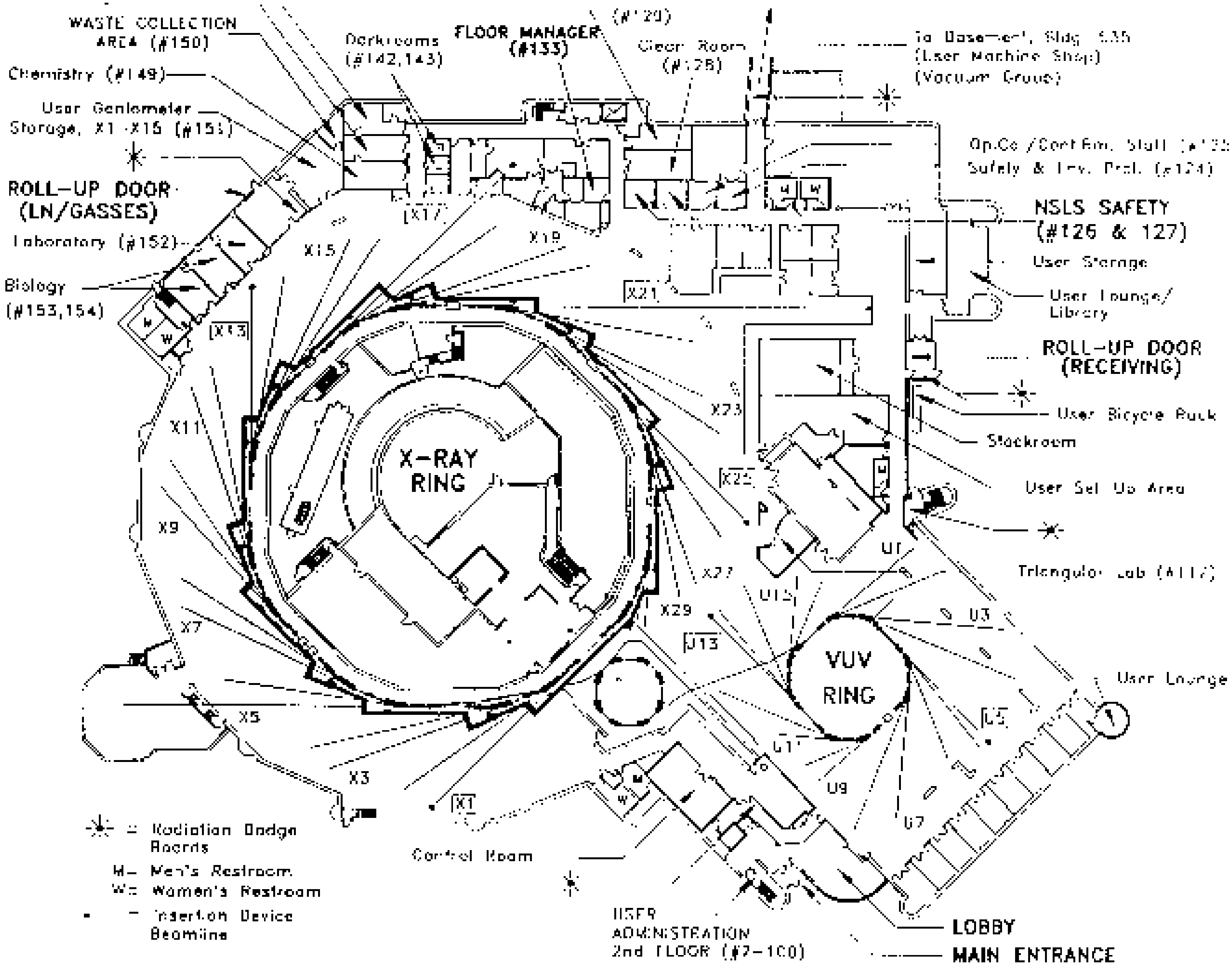
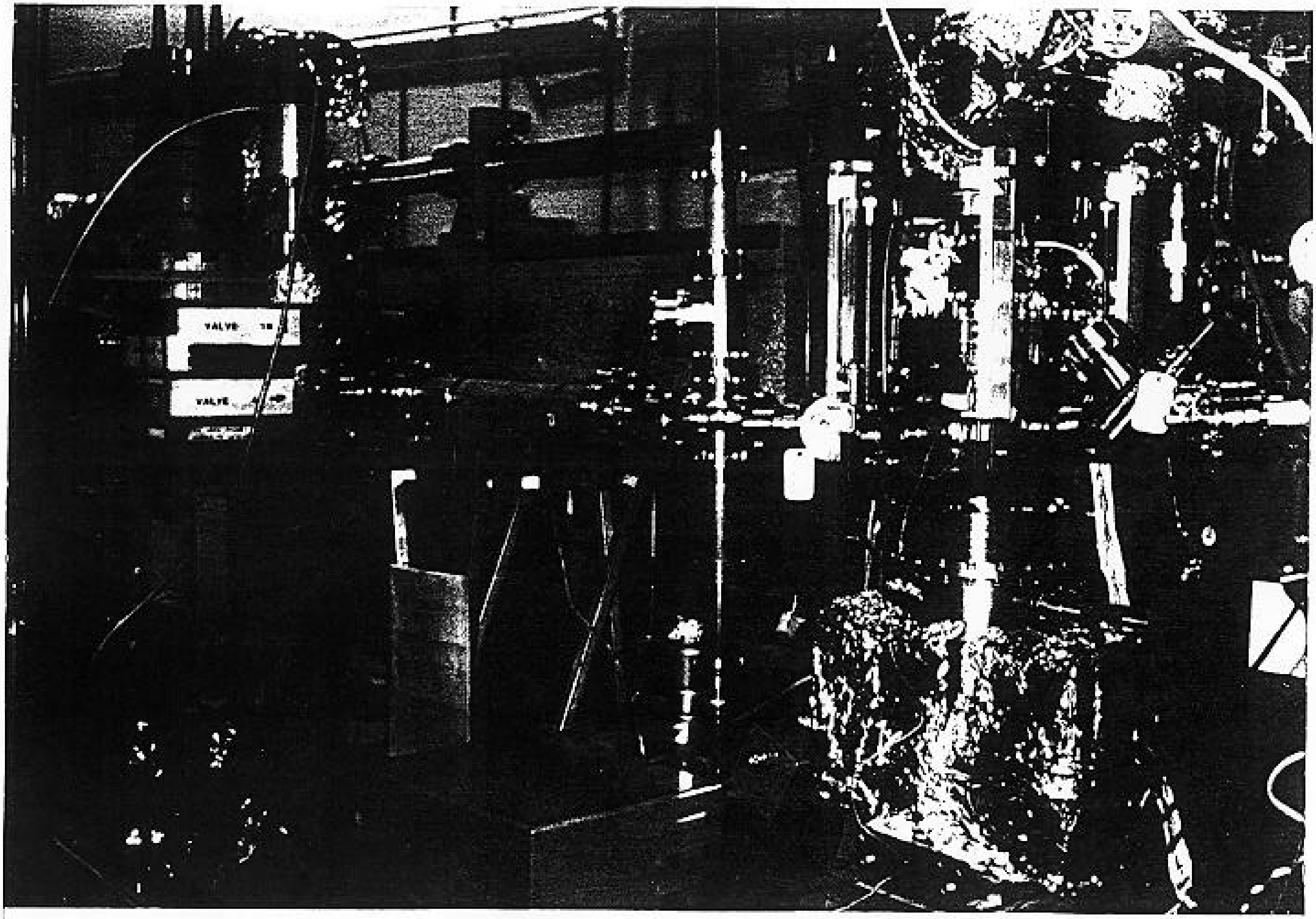
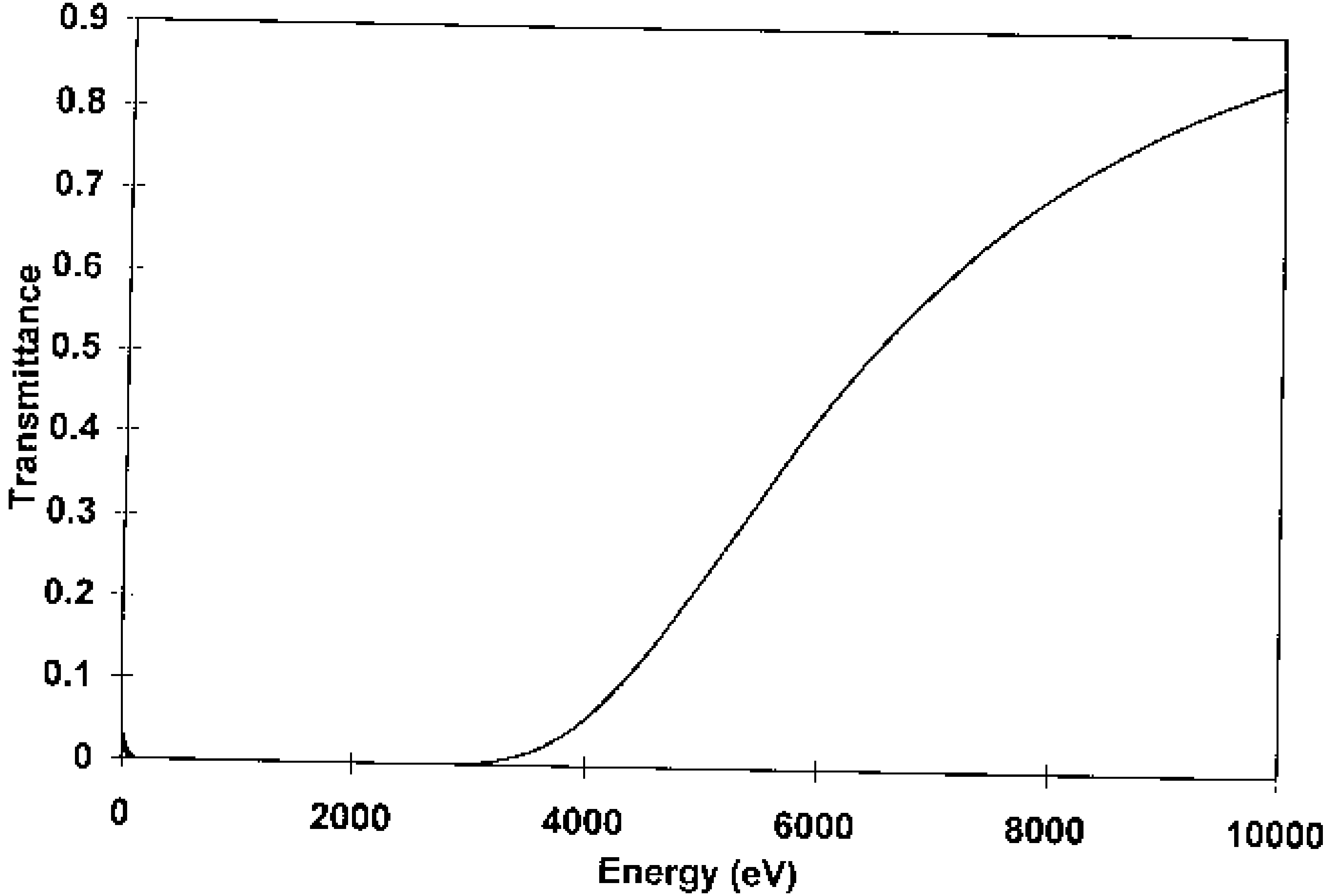
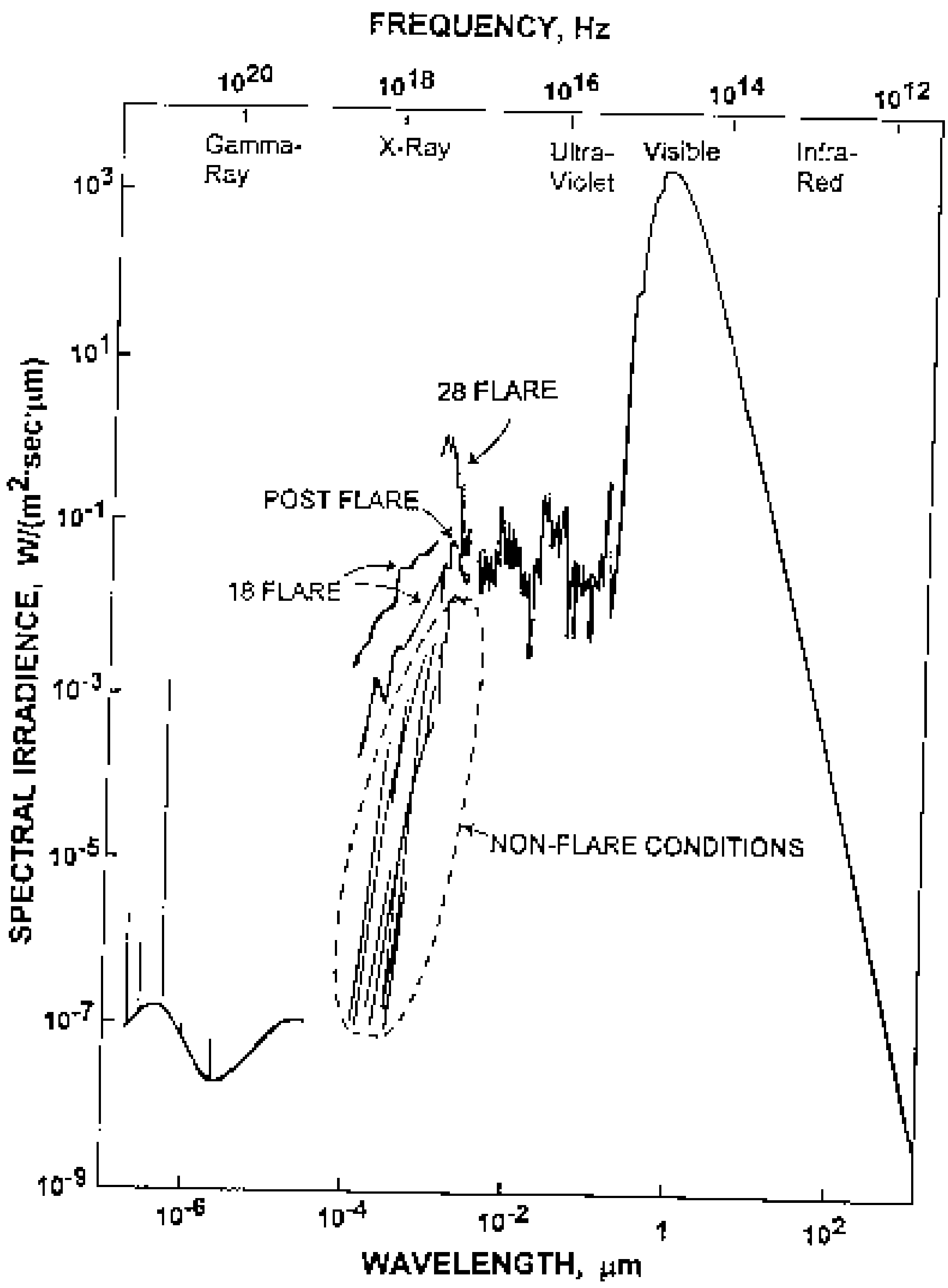


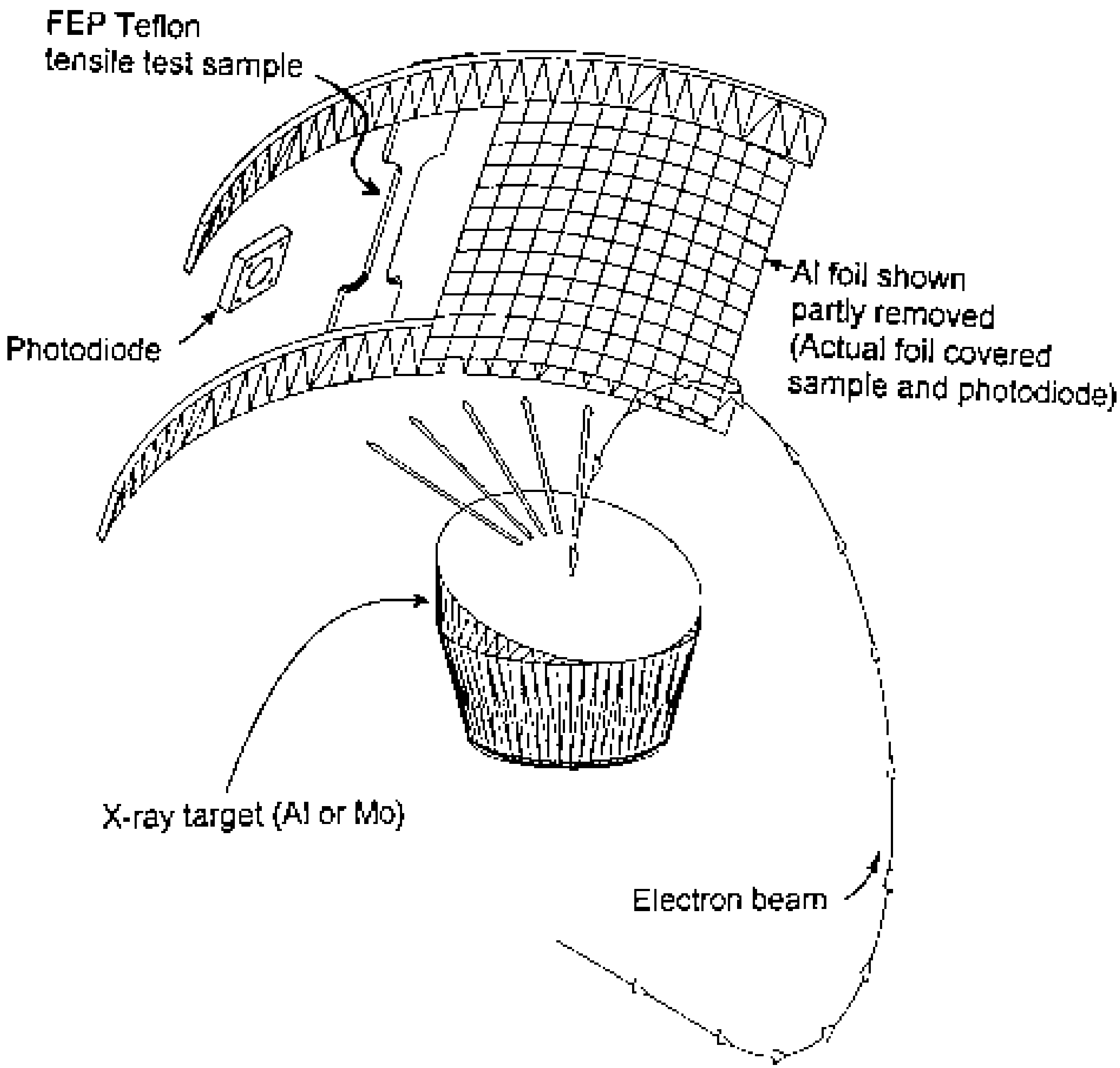
Figure 1. Floor plan of the National Synchrotron Light Source experimental area.


VALVE
VALVE

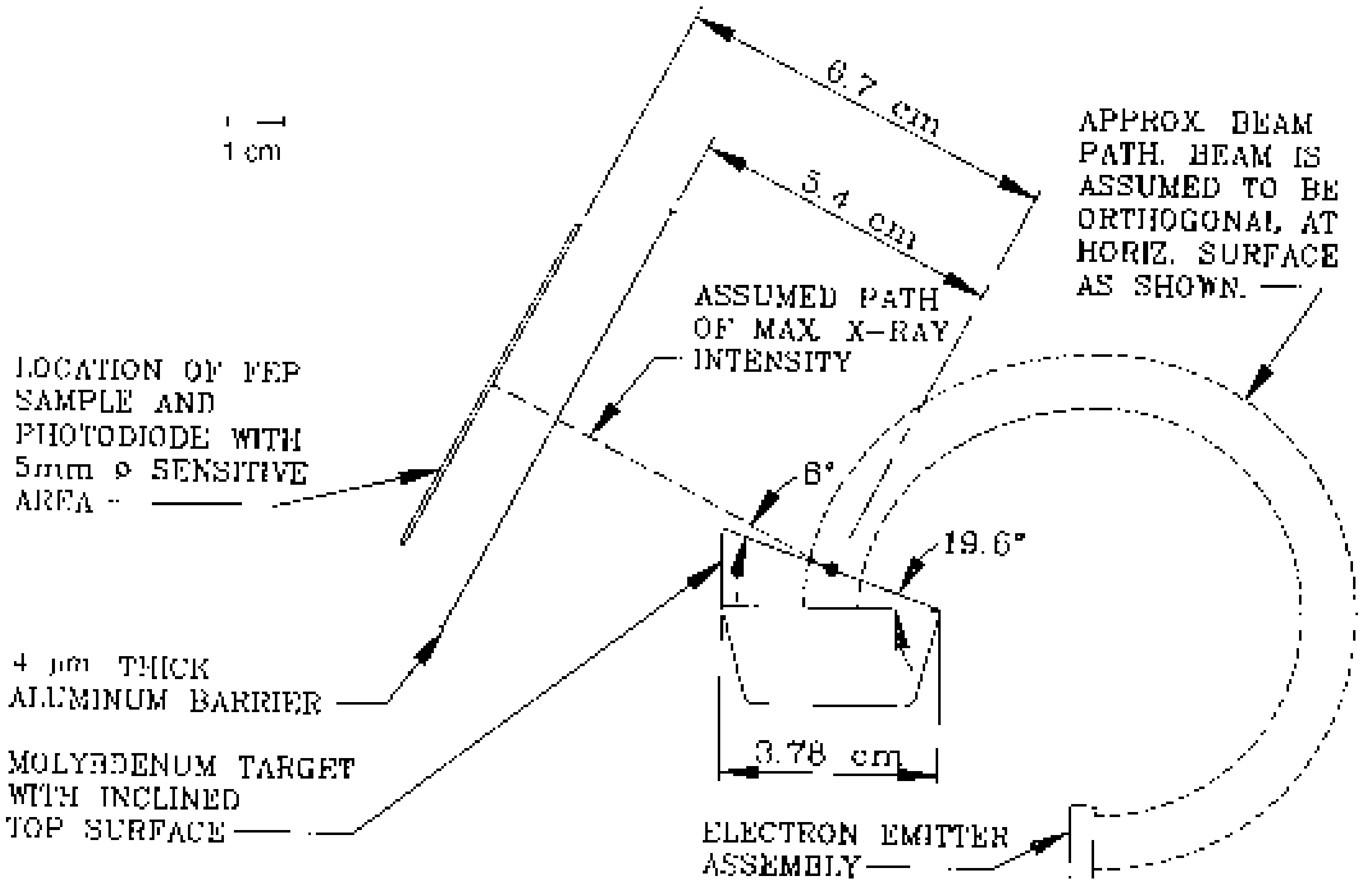


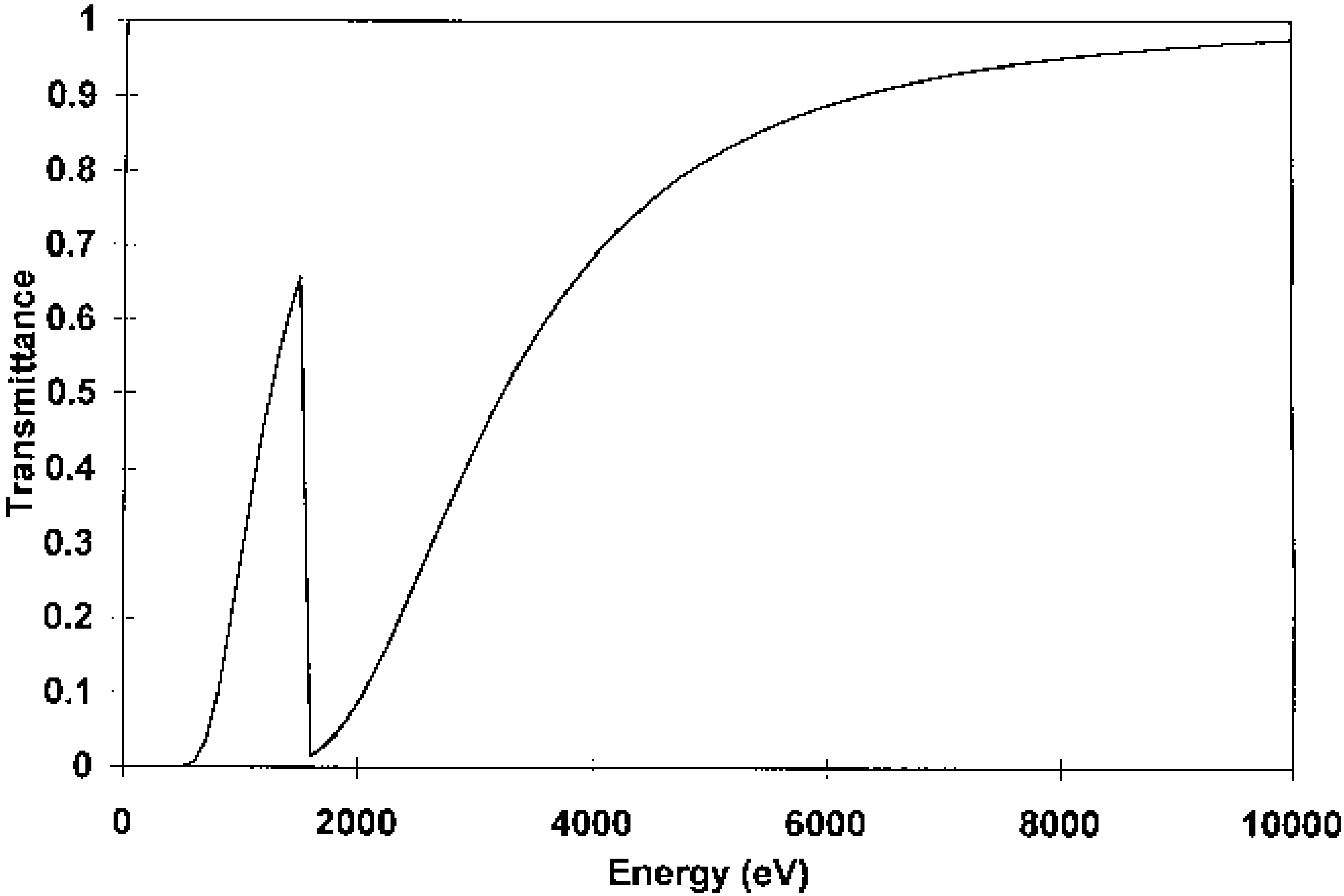
Transmittance
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
2000
4000
6000
8000
10000
Energy (eV)

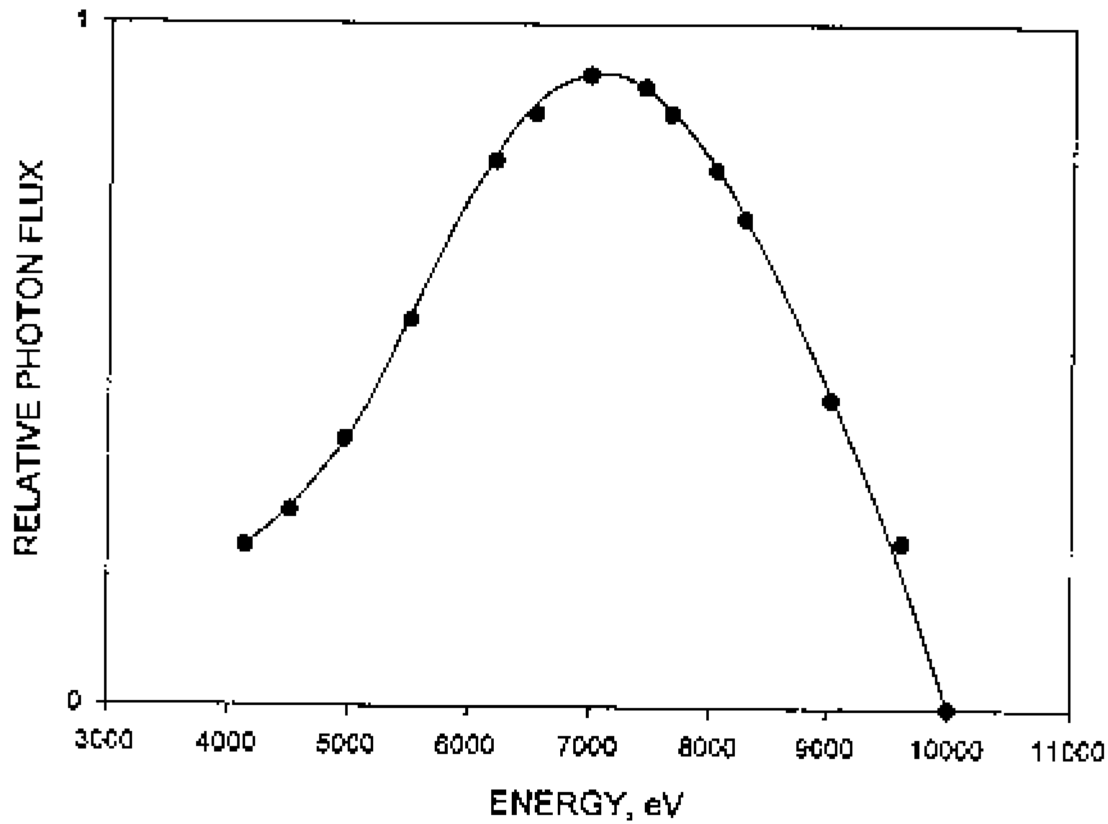

FREQUENCY, Hz
10^20
10^18
10^16
10^14
10^12
Gamma-Ray
X-Ray
Ultra-Violet
Visible
Infra-Red
SPECTRAL IRRADIENCE, W/(m^2·sec·µm)
10^3
10^1
10^-1
10^-3
10^-5
10^-7
10^-9
28 FLARE
POST FLARE
18 FLARE
NON-FLARE CONDITIONS
10^-6
10^-4
10^-2
1
10^2
WAVELENGTH, µm



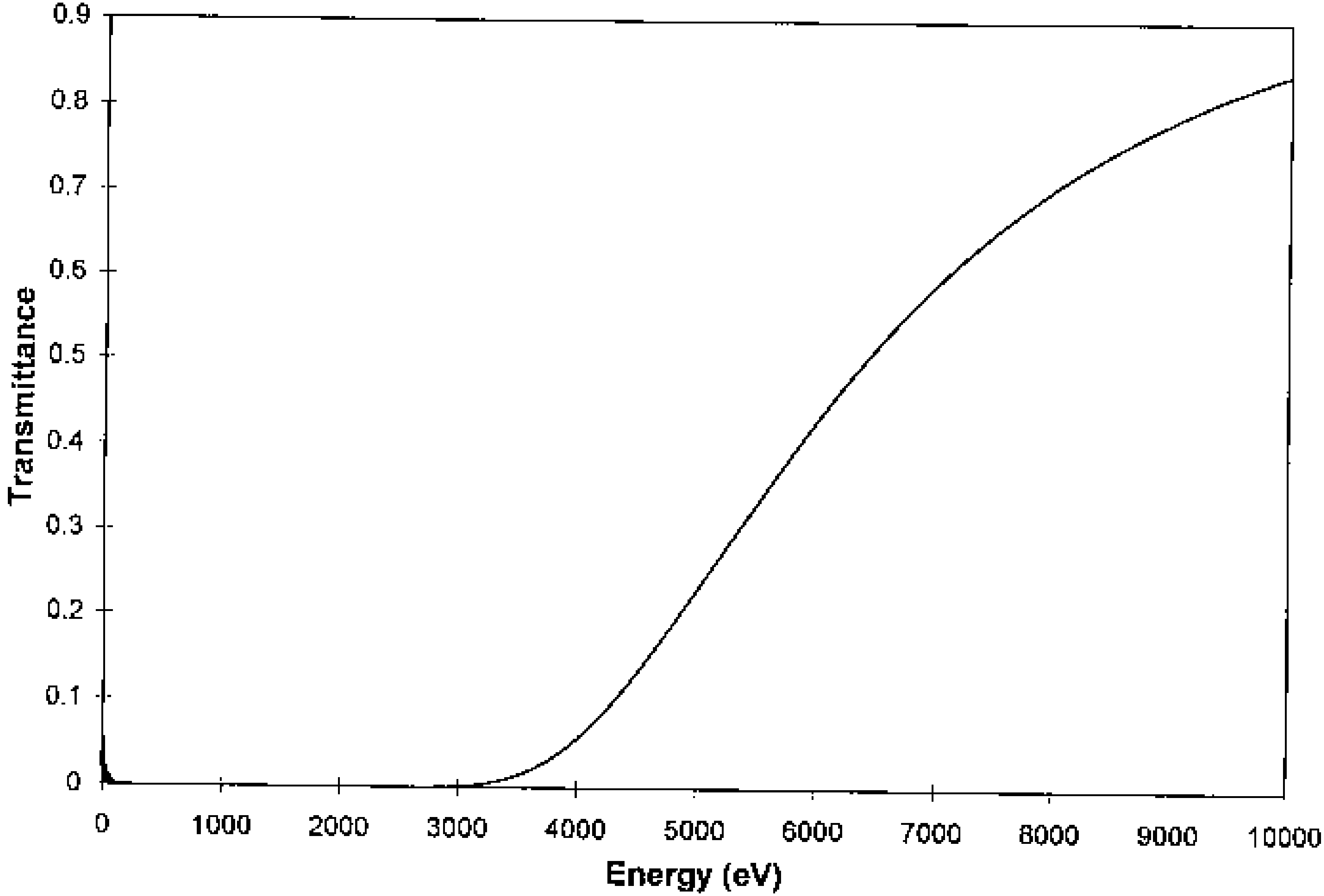
FEP Teflon
tensile test sample
Al foil shown
partly removed
(Actual foil covered
sample and photodiode)
Photodiode
X-ray target (Al or Mo)
Electron beam


1 cm
6.7 cm
5.4 cm
APPROX. BEAM PATH. BEAM IS ASSUMED TO BE ORTHOGONAL AT HORIZ. SURFACE AS SHOWN.
ASSUMED PATH OF MAX. X-RAY INTENSITY
LOCATION OF FEP SAMPLE AND PHOTODIODE WITH 5mm ø SENSITIVE AREA
6°
19.6°
4 μm THICK ALUMINUM BARRIER
3.78 cm
MOLYBDENUM TARGET WITH INCLINED TOP SURFACE
ELECTRON EMITTER ASSEMBLY


1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Transmittance
0
2000
4000
6000
8000
10000
Energy (eV)



1
0
RELATIVE PHOTON FLUX
3000
4000
5000
6000
7000
8000
9000
10000
11000
ENERGY, eV

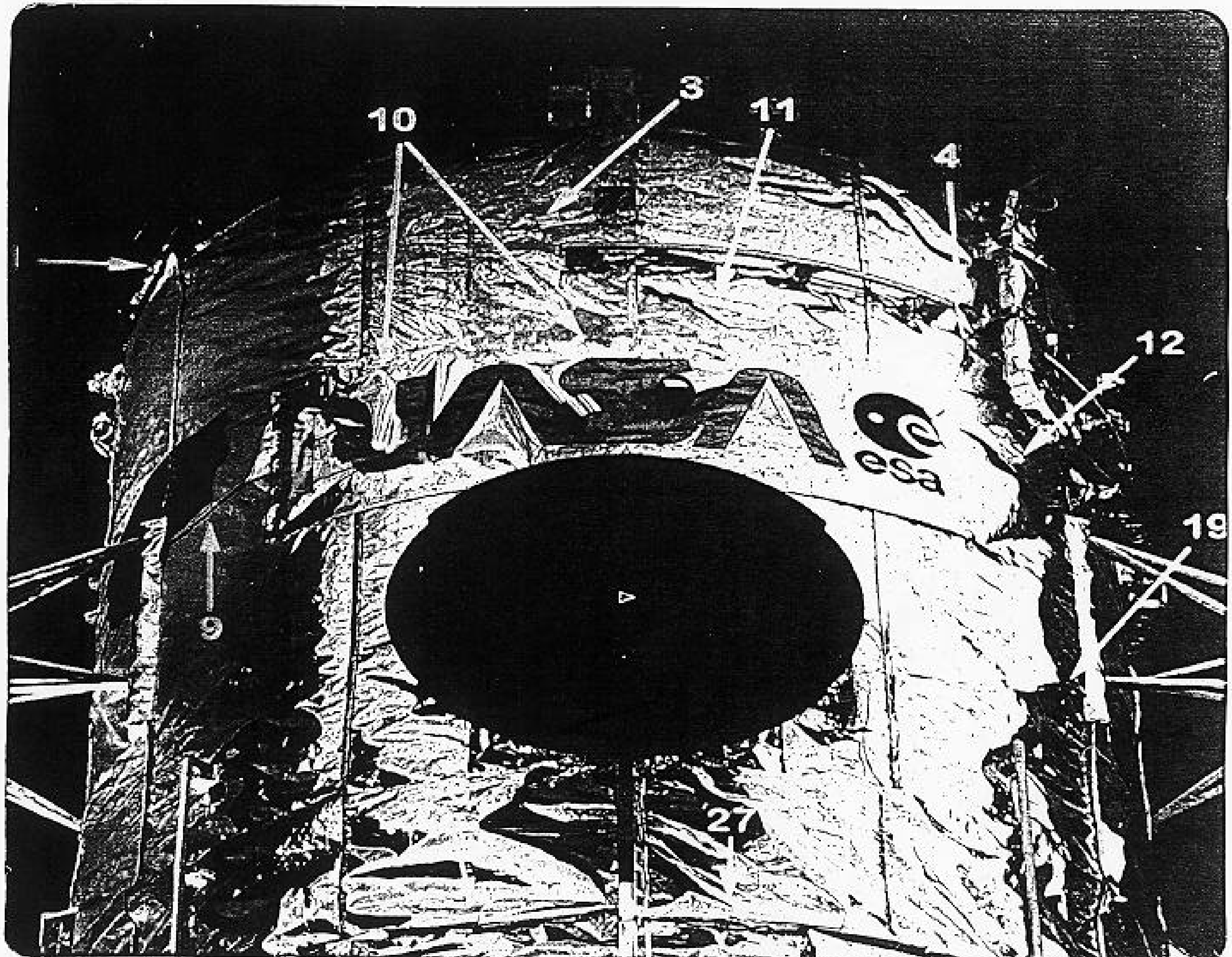


0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Transmittance
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
Energy (eV)

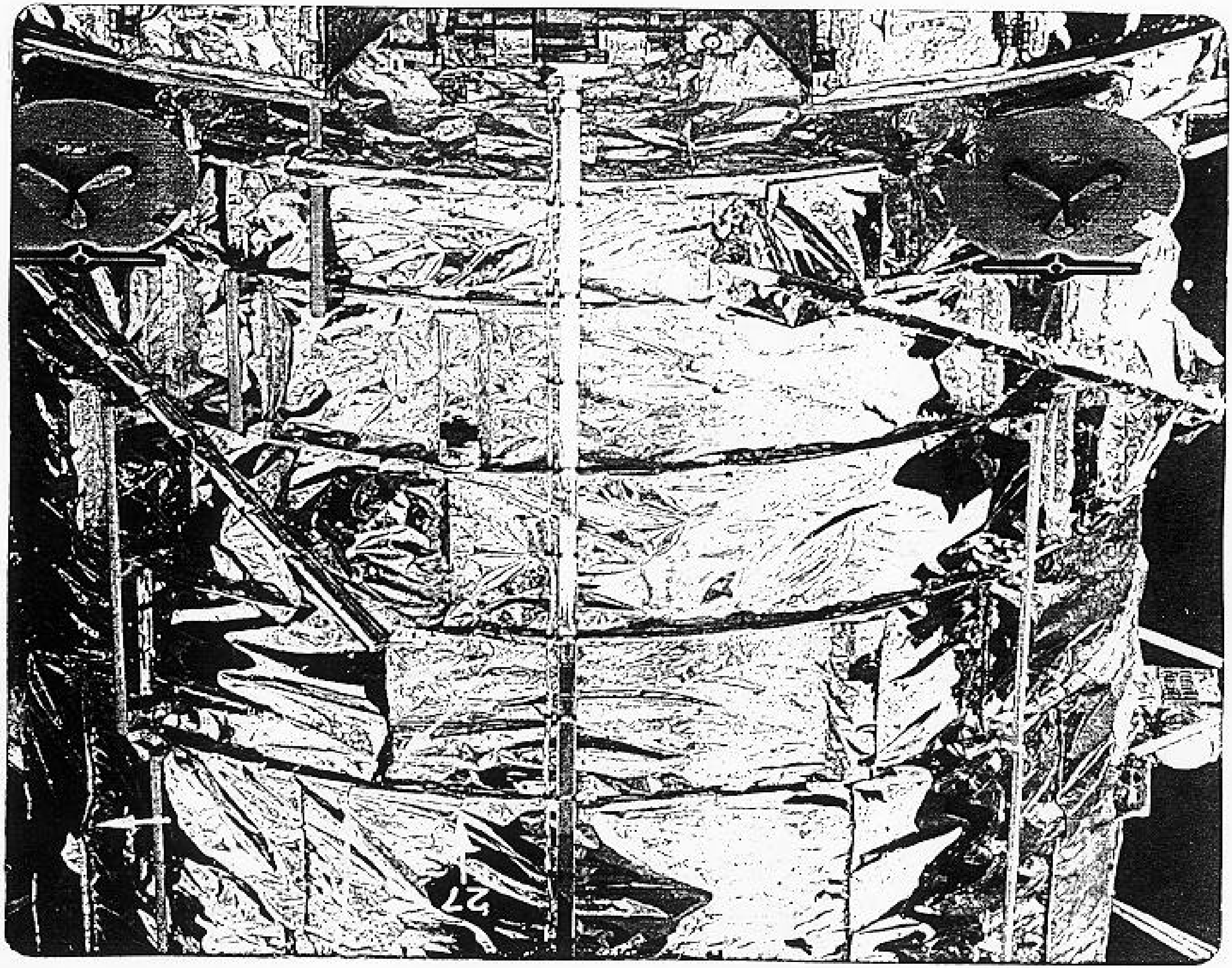
Table I. FEP Teflon Soft x-ray and Tensile Properties Results

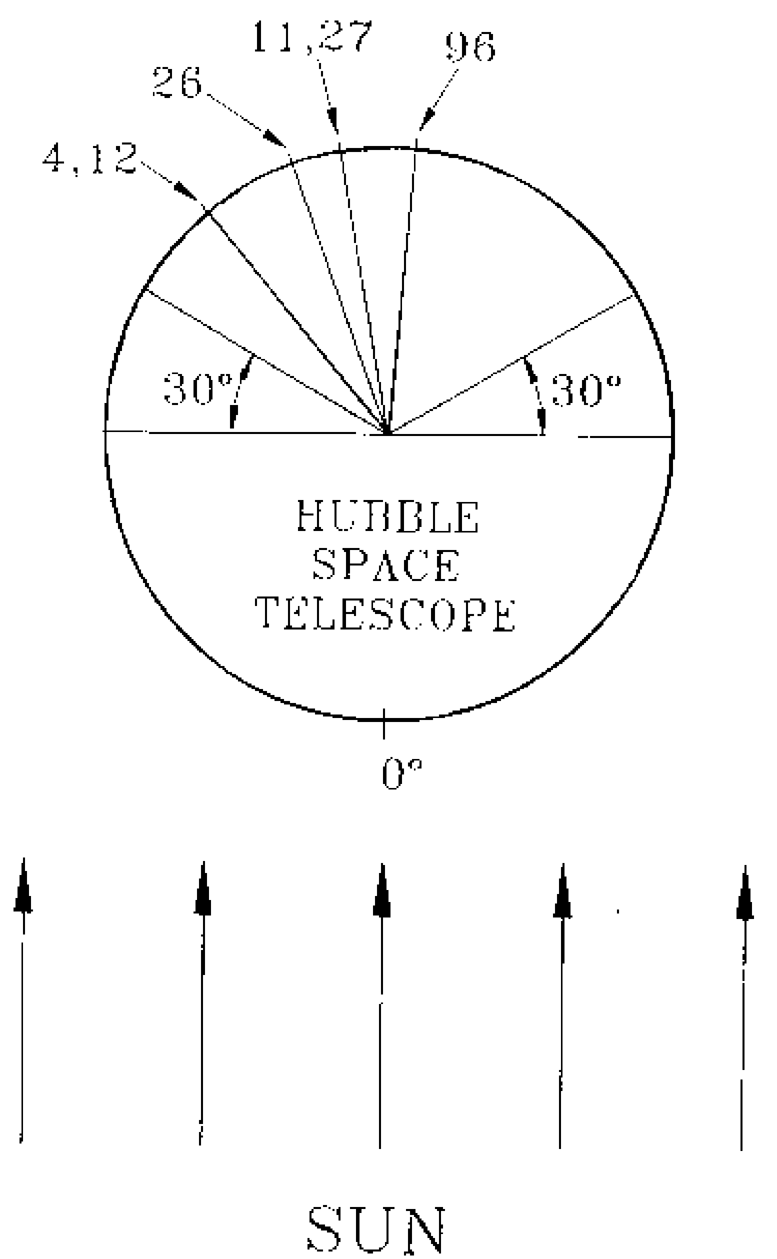
5 mil FEP Sample Description	E-Beam Energy, keV	Target	Al Foil Barrier	Laboratory Soft X-ray Exposure Time, sec	Soft X-ray Fluence, J/m²	UTS, MPa (psi)	% Elongation (relative to Pristine FEP)
Pristine Al-FEP (Ave. of 9)	-	-	-	-	0	19.3 ± 1.8 (2792 ± 263)	198.2 ± 21.5 (100%)
HST Al-FEP SM1 (11,339 ESH)	-	-	-	-	131.8 [b]	13.6 (1973)	42.2 (21.3%)
HST Al-FEP SM1 (11,339 ESH) + 1191 thermal cycles (-100 to +50°C)	-	-	-	-	131.8 [b]	14.7 (2136)	27.7 (14.0%)
Soft X-ray Al-FEP	8	Angled Mo (No cooling)	None	18,000	≈14,500 [c]	14.8 ± 0.1 (2143 ± 18)	21.0 (10.6%)
Soft X-ray Al-FEP SM3-2010 exposure (Ave. of 16)	10	Angled Mo Watercooled	4 μm [a]	390 ± 51	457 ± 50 [d]	16.2 ± 1.3 (2349 ± 194)	182.7 ± 27.2 (92.2%)
Pristine Ag-FEP	-	-	-	-	0	18.9 ± 2.5 (2741 ± 360)	539 ± 95 (100%)
Soft X-ray Ag-FEP (Ave. of 5)	8	Angled Al (No cooling)	None	18,000	≈4100 [c]	13.7 ± 0.3 (1981 ± 42)	141 ± 31 (26.2%)

[a] Top layer of Al foil barrier degraded
[b] Based on in-space measurements on the GOES spacecraft
[c] Based on photodiode measurements from the 390 sec exposure, below, corrected for energy and lack of Al foil barrier and target atomic number
[d] Based on photodiode measurements

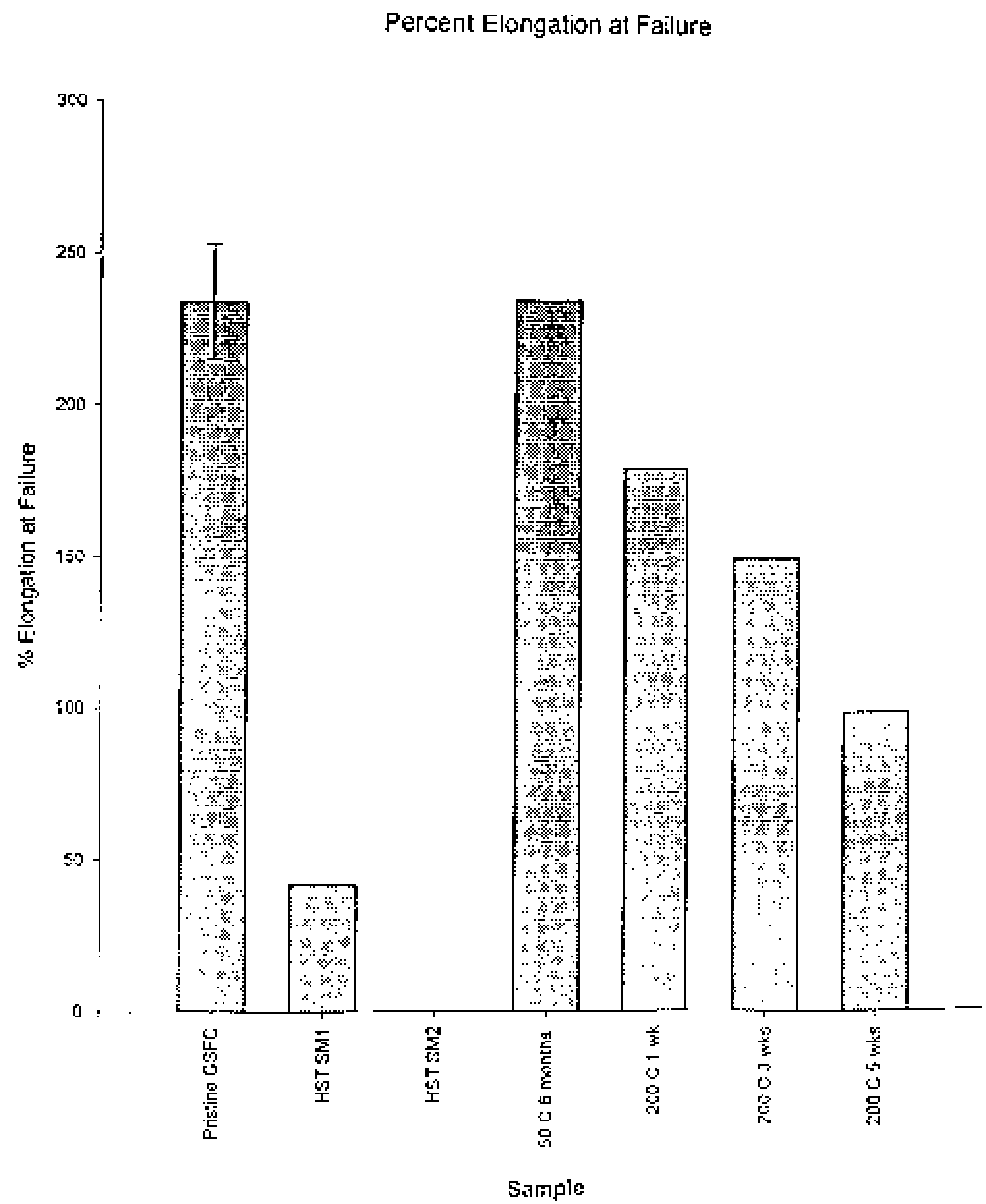


10
3
11
4
12
esa
19
9
27

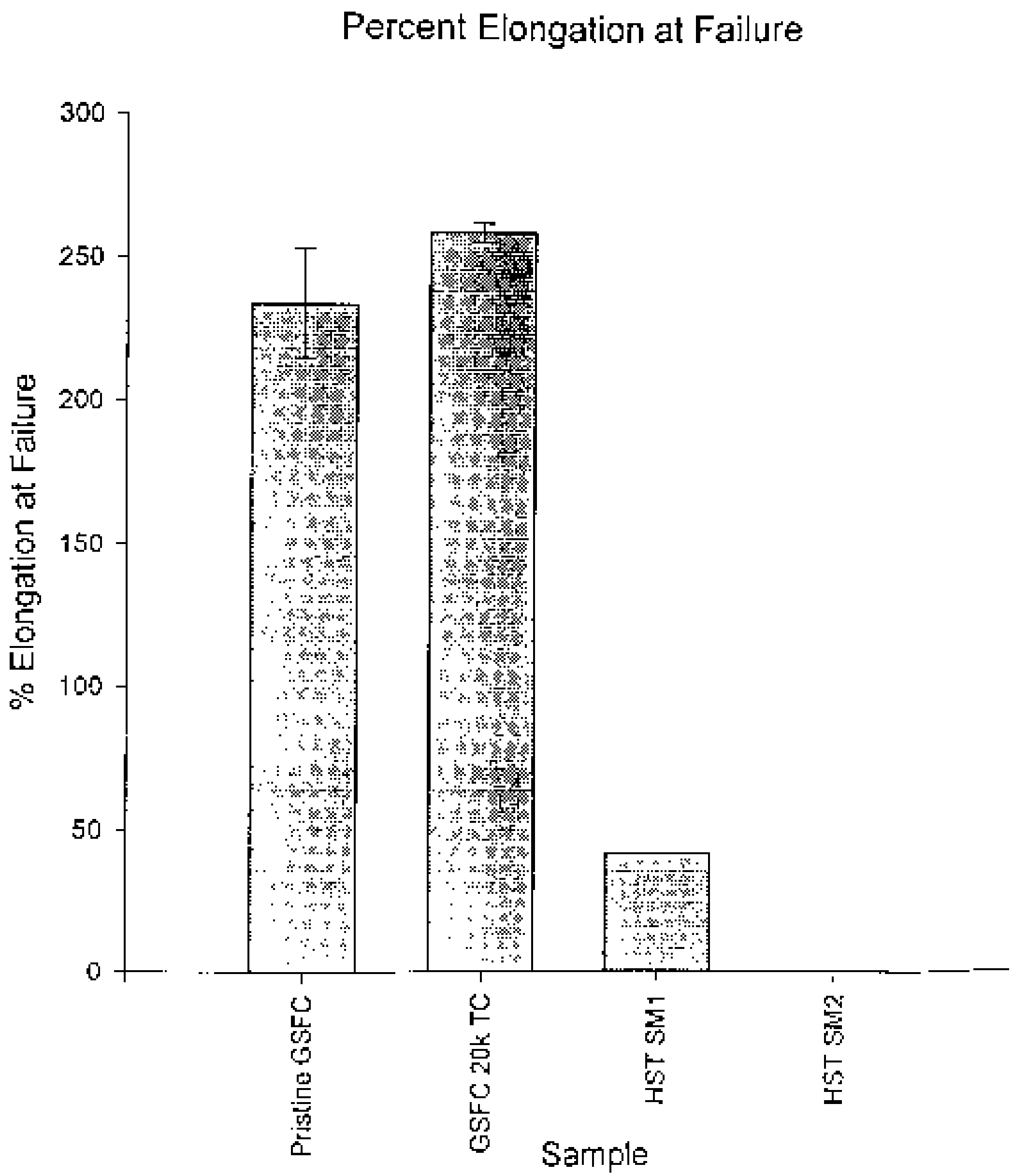




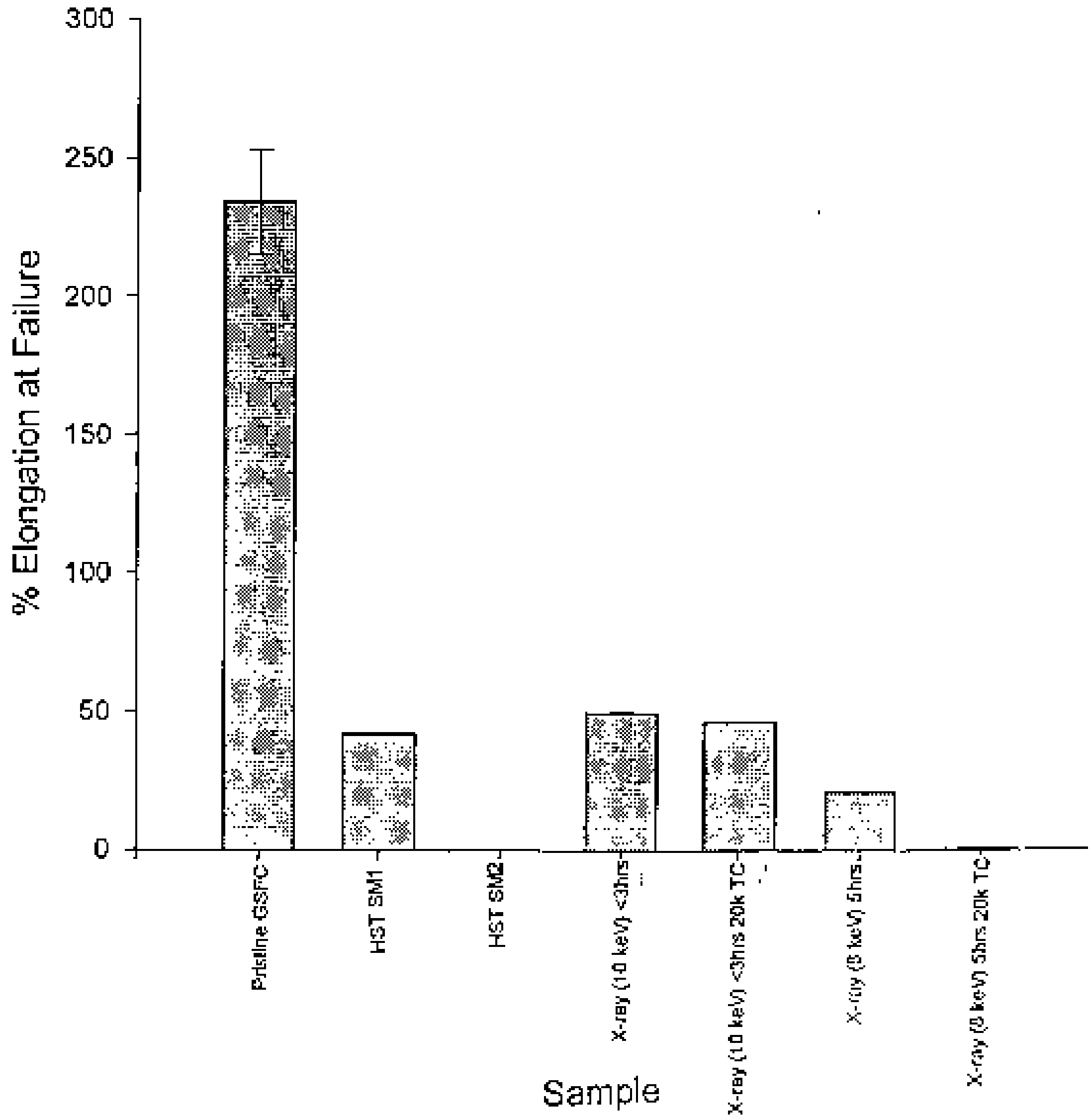
11,27
96
26
4,12
30°
30°
HUBBLE
SPACE
TELESCOPE
0°
SUN

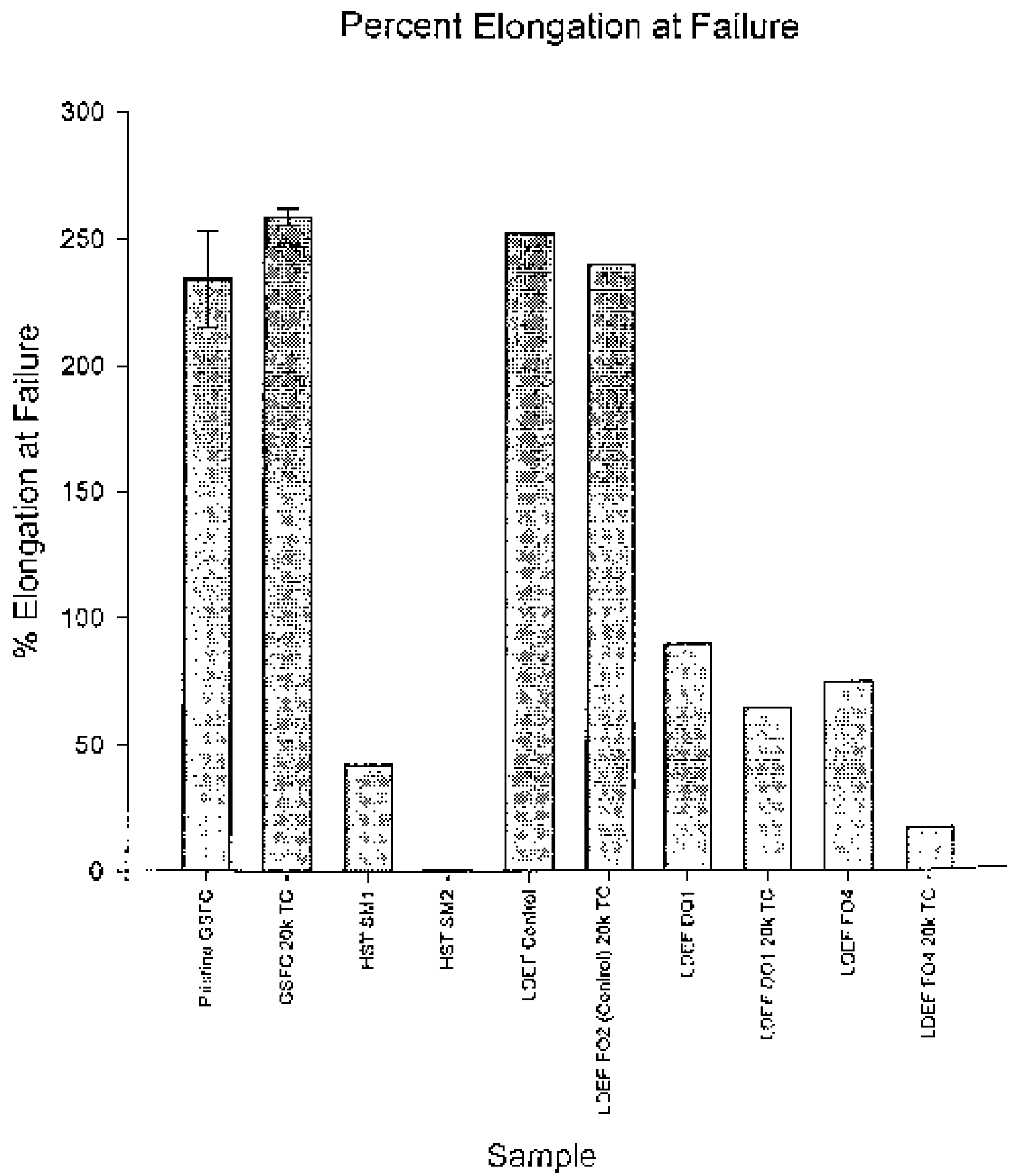


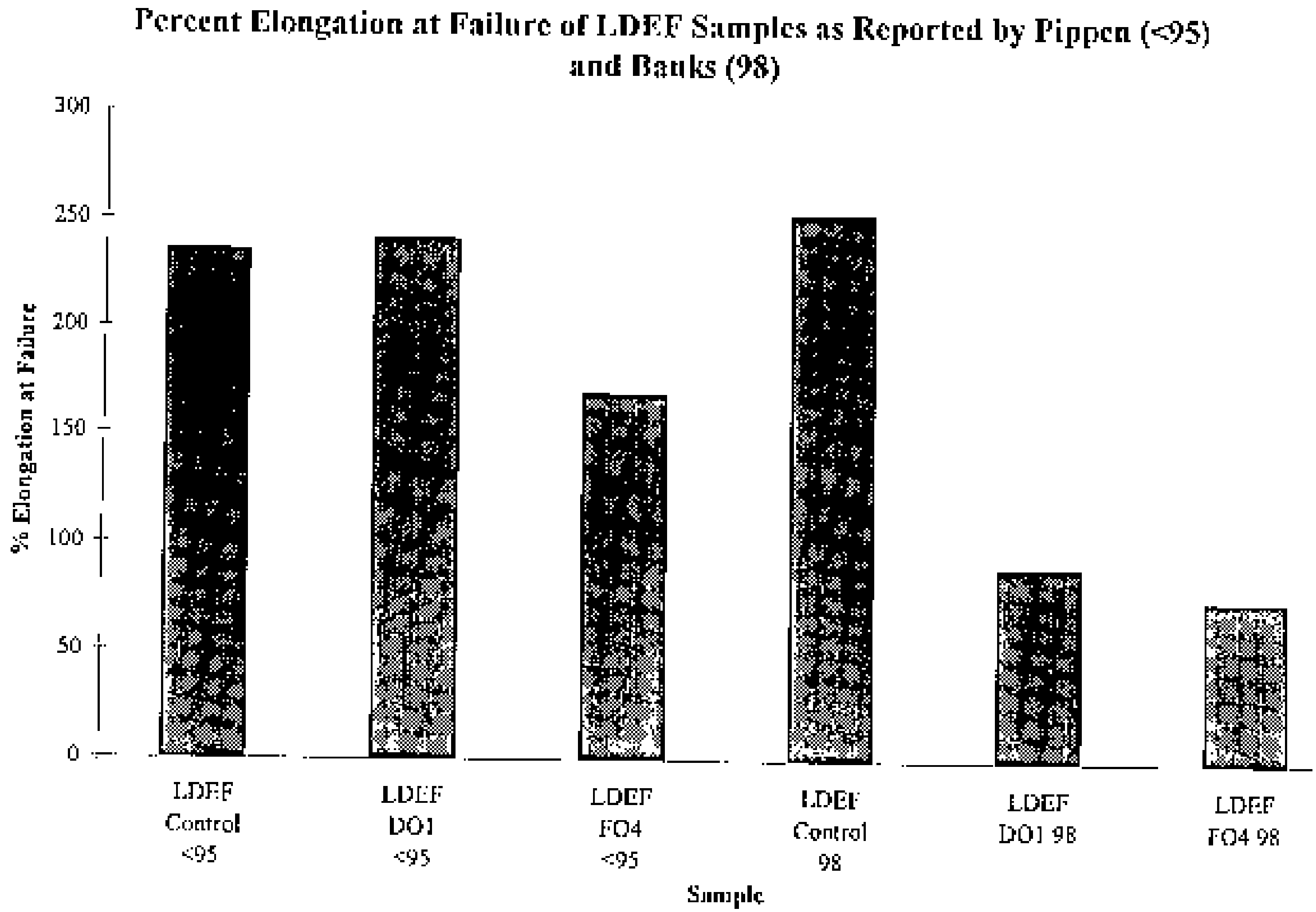
Percent Elongation at Failure
% Elongation at Failure
300
250
200
150
100
50
0
Pristine GSFC
HST SM1
HST SM2
50 C 6 months
200 C 1 wk
200 C 3 wks
200 C 5 wks
Sample


Percent Elongation at Failure
% Elongation at Failure
300
250
200
150
100
50
0
Pristine GSFC
GSFC 20k TC
HST SM1
HST SM2
Sample

Percent Elongation at Failure




Percent Elongation at Failure
% Elongation at Failure
300
250
200
150
100
50
0
GSFC 20k TC
HST SM1
HST SM2
LDEF Control
LDEF FO2 (Control) 20k TC
LDEF DO1
LDEF DO1 20k TC
LDEF FO4
LDEF FO4 20k TC
Sample

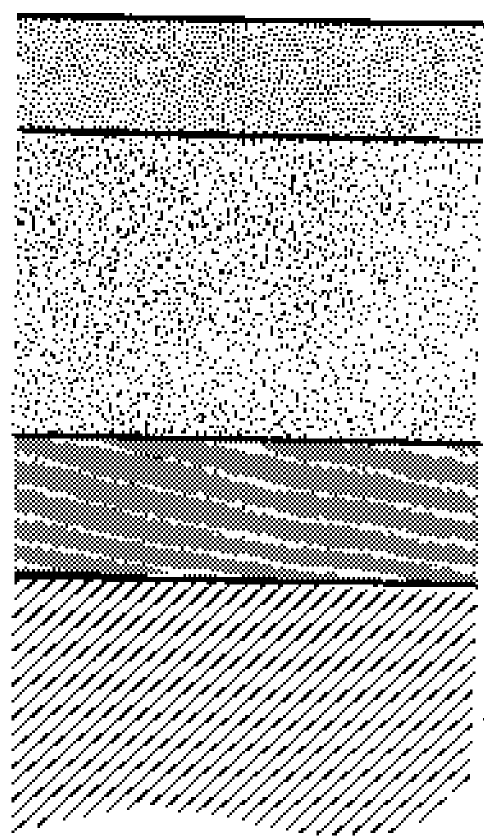


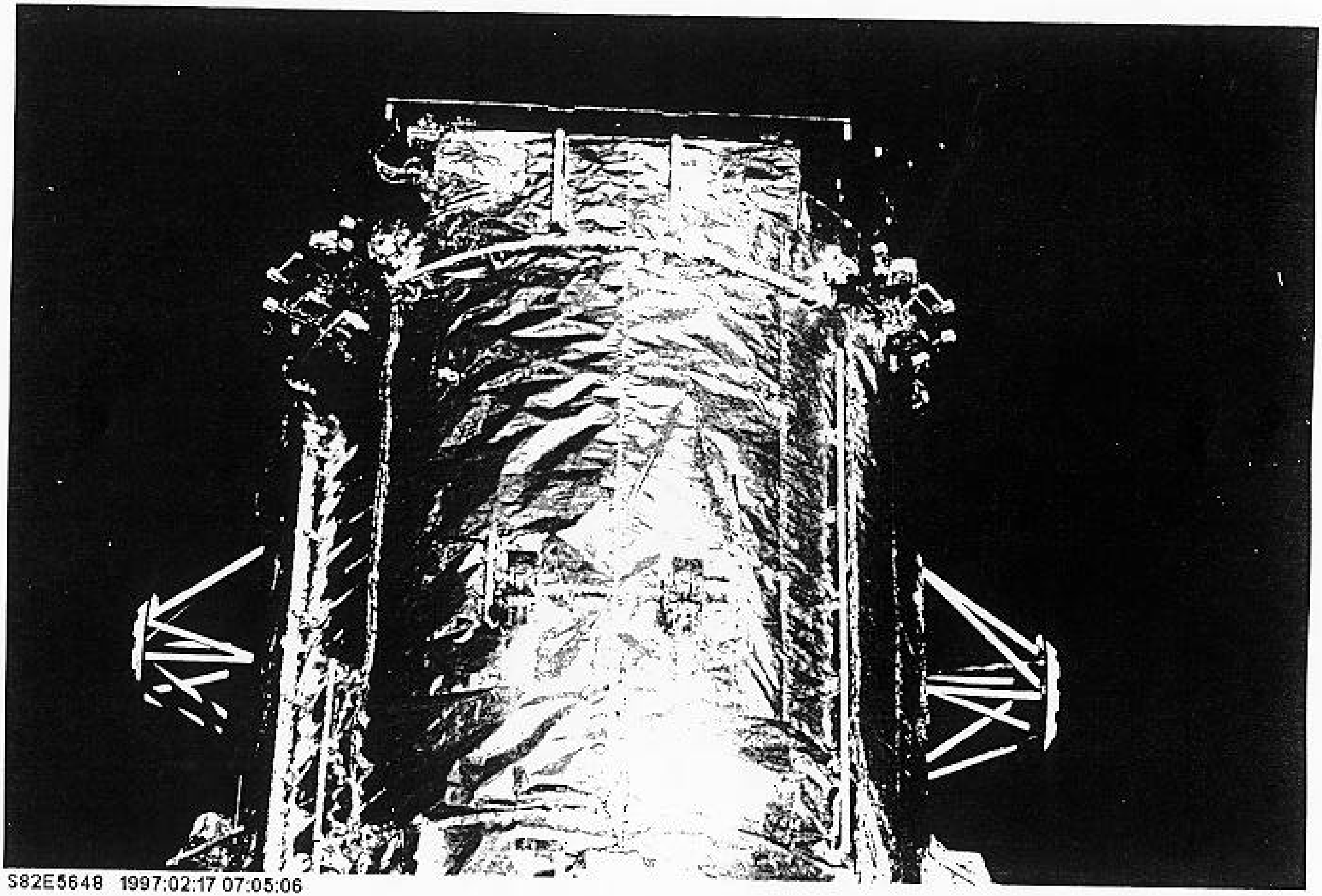
Percent Elongation at Failure of LDEF Samples as Reported by Pippen (<95) and Banks (98)
300
250
200
150
100
50
0
% Elongation at Failure
LDEF Control <95
LDEF DO1 <95
LDEF FO4 <95
LDEF Control 98
LDEF DO1 98
LDEF FO4 98
Sample

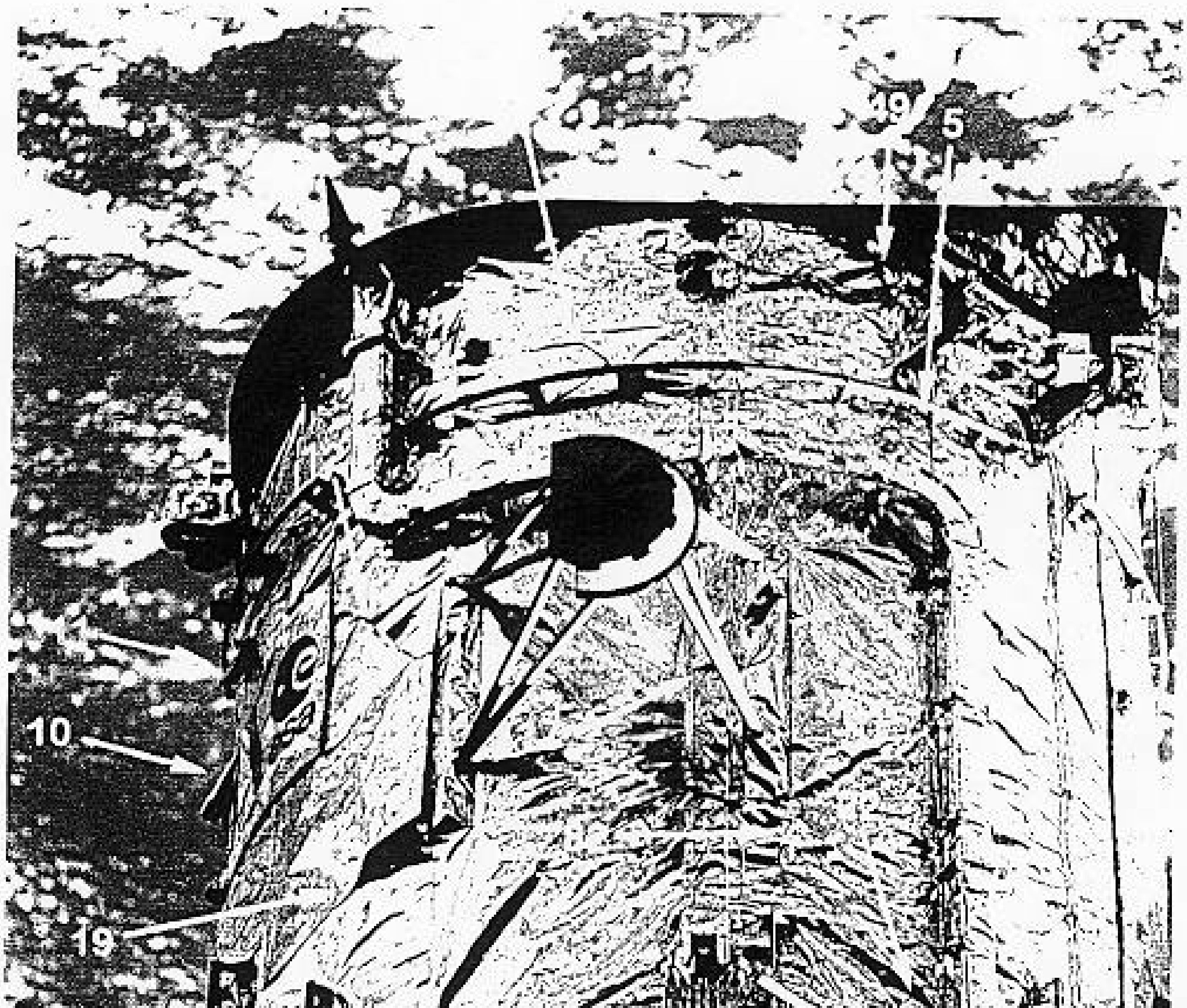
HUBBLE SPACE TELESCOPE

HANDRAIL PAINT

HUBBLE SPACE TELESCOPE
HANDRAIL PAINT



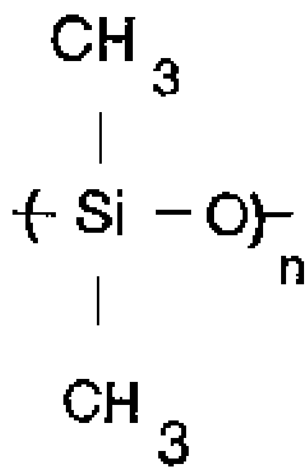

S82E5648 1997:02:17 07:05:06



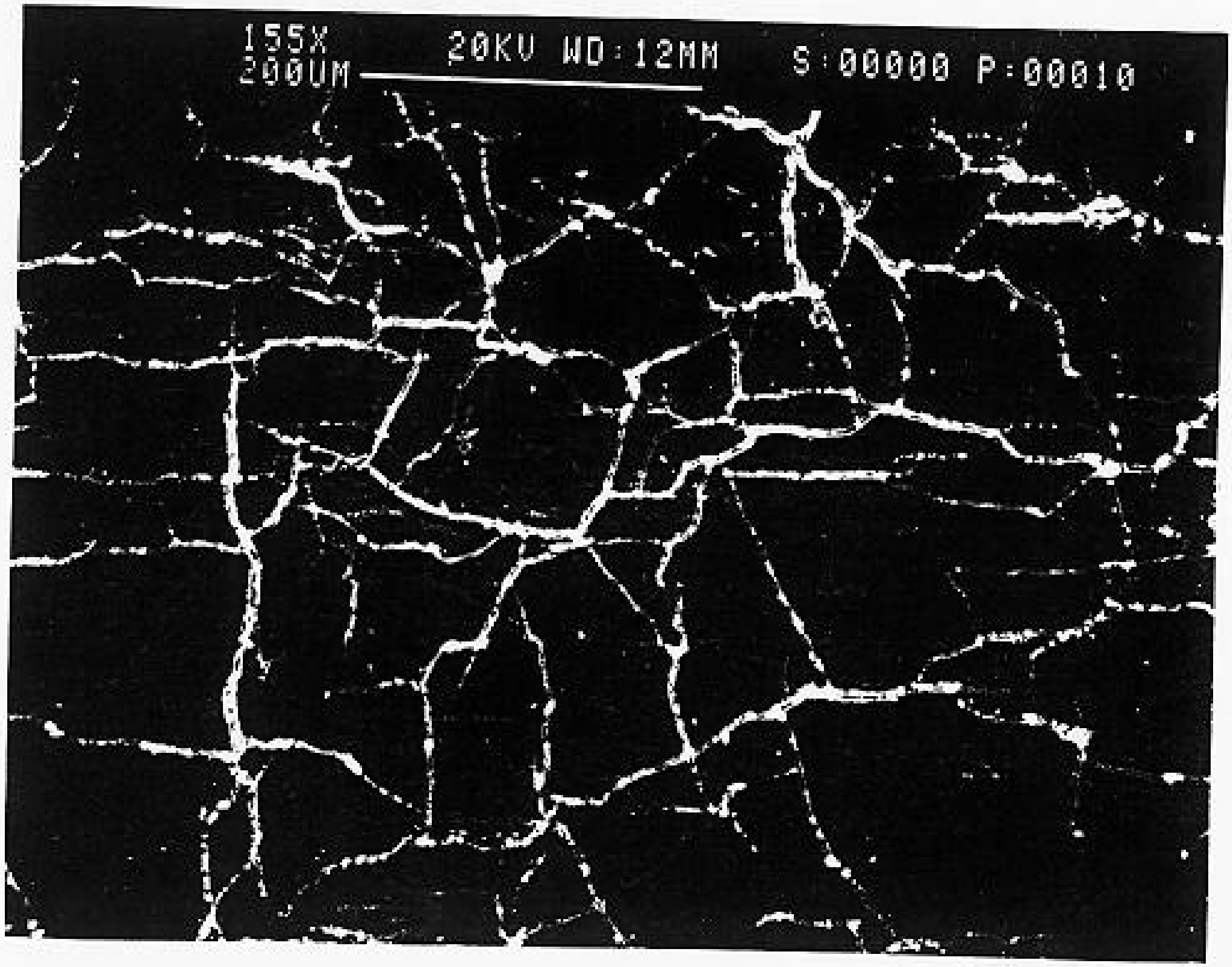
49
5
10
19

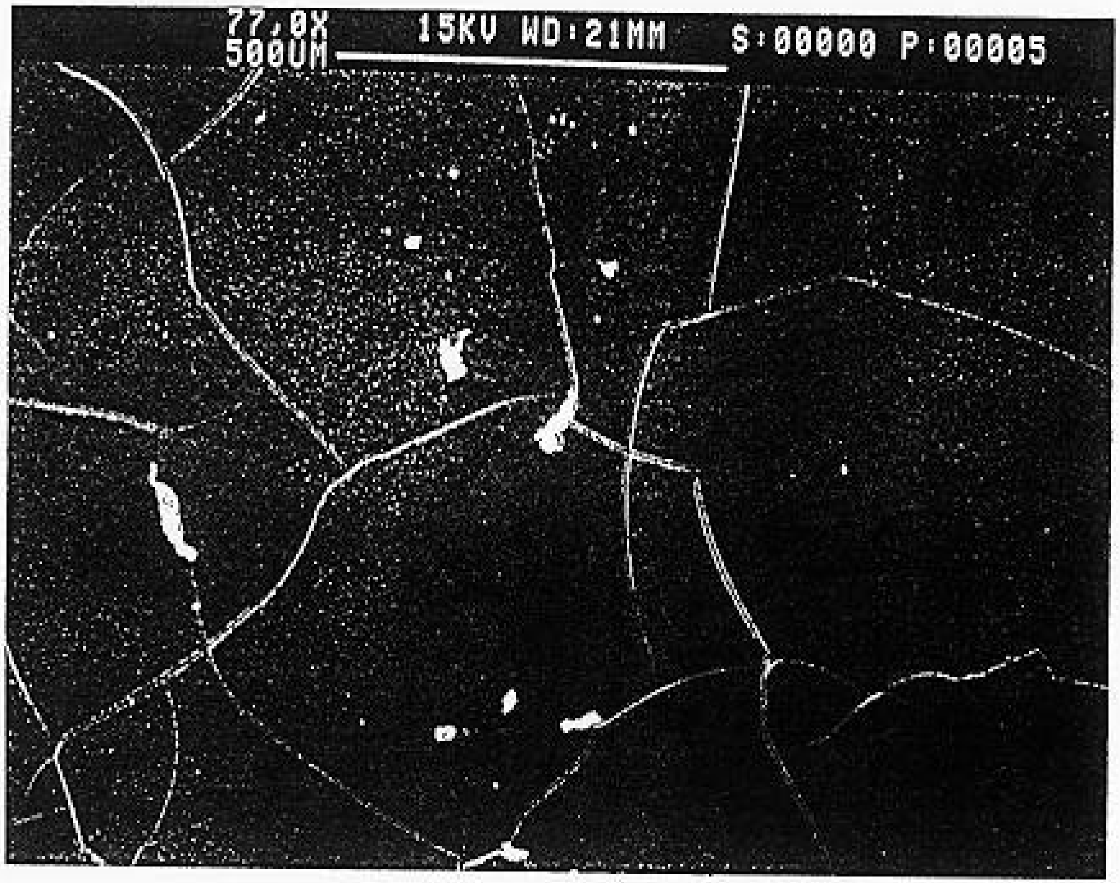

T*R. 00:54.50.11

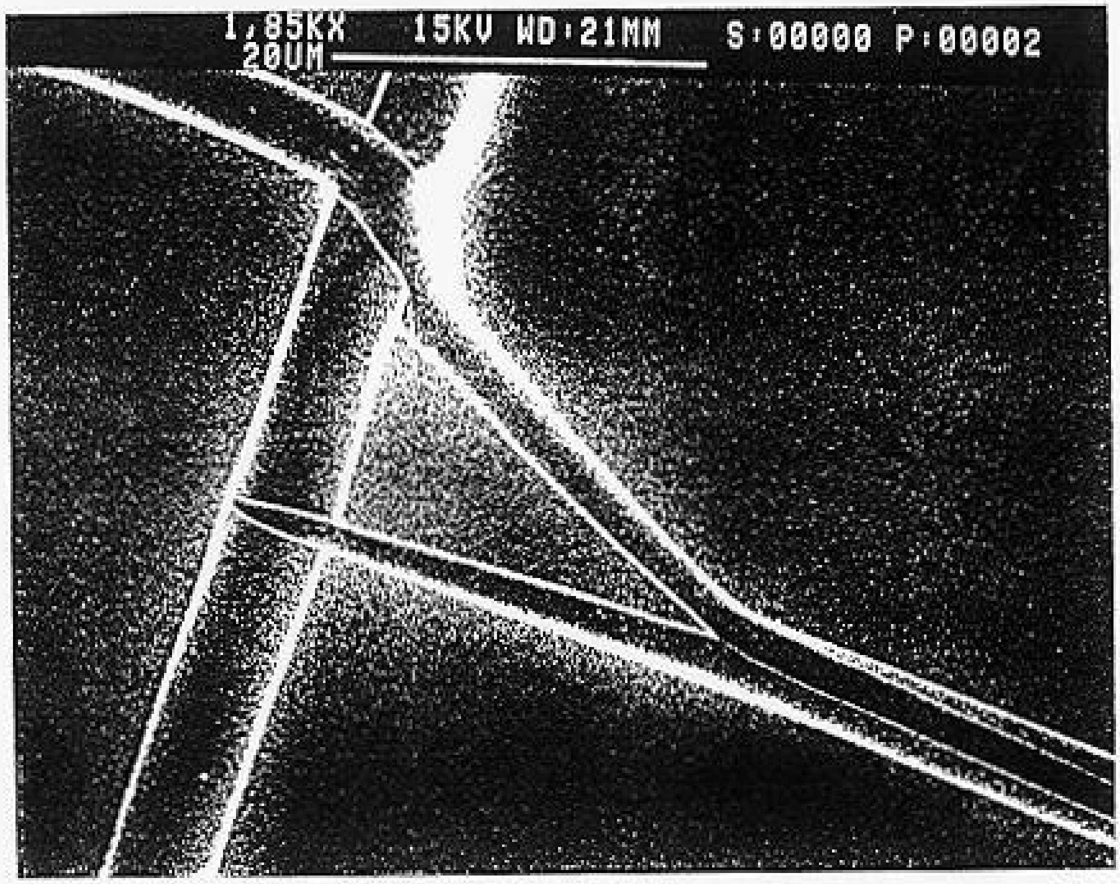
Silicone Rubber



Polydimethylsiloxane


155X
200UM
20KV WD:12MM
S:00000 P:00010


77.0X
500UM
15KV WD:21MM
S:00000 P:00005

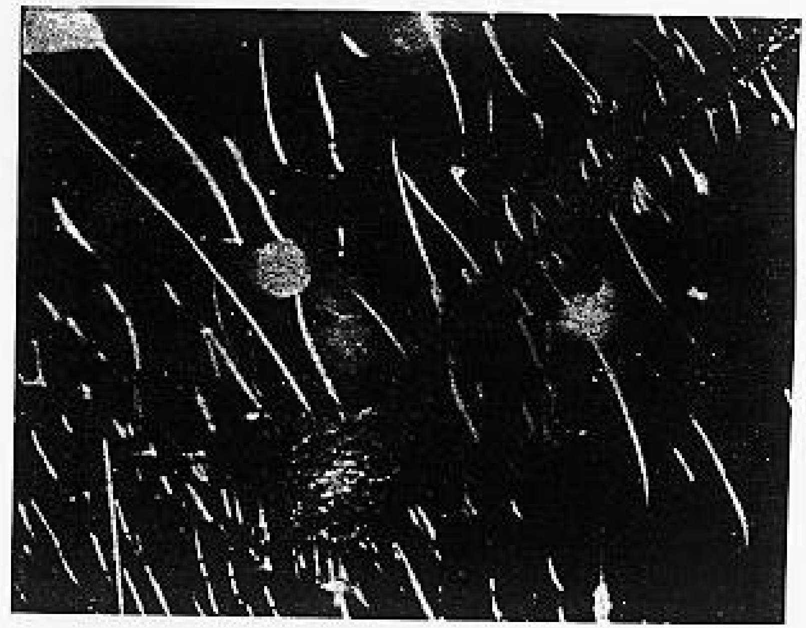

1,85KX 15KV WD:21MM S:00000 P:00002
20UM

Uncoated DC 93-500 Silicone

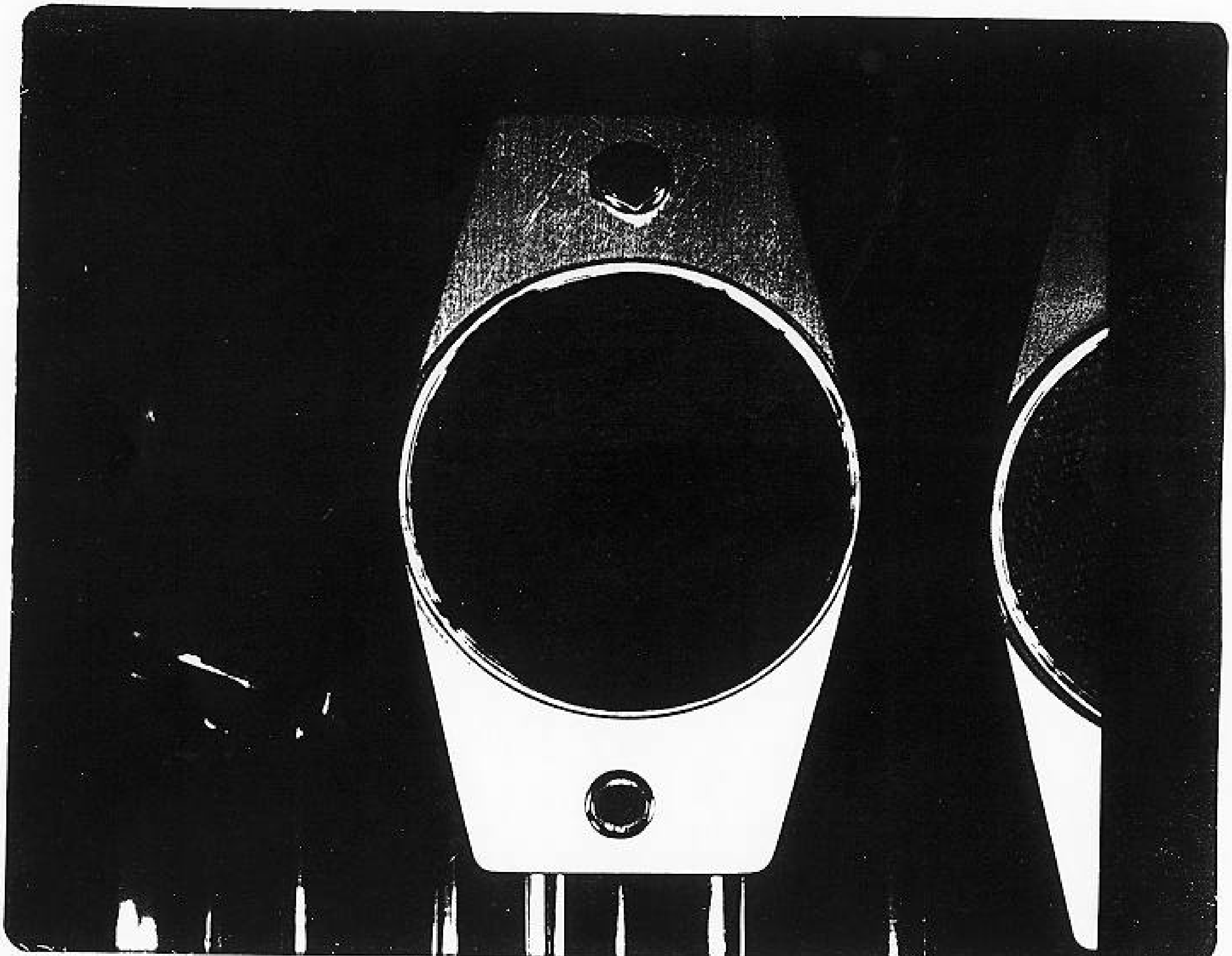
Exposed to LEO Atomic Oxygen on STS-46

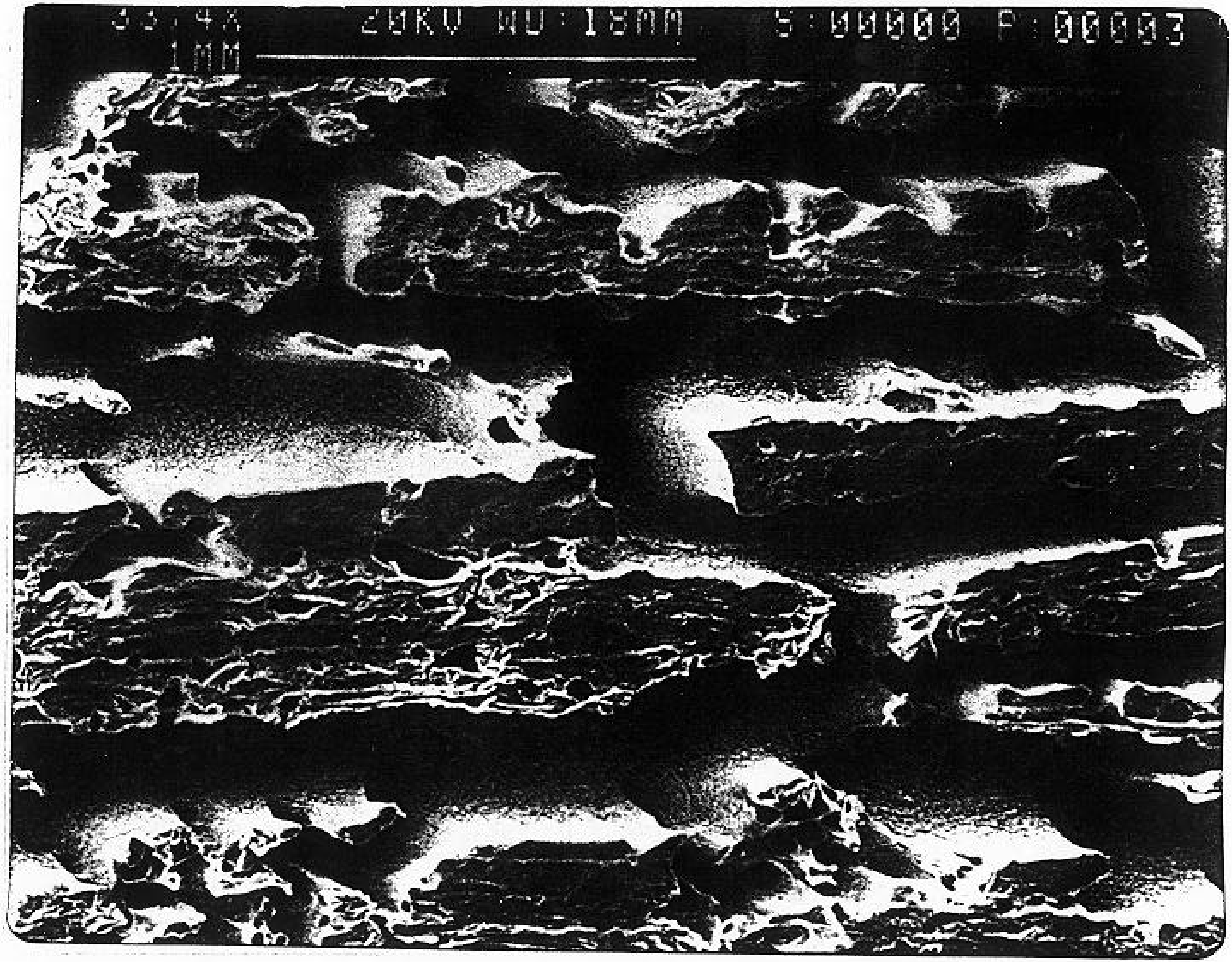
F= 2.3 x 10^{20} atoms/cm^2

Pre-flight 63X

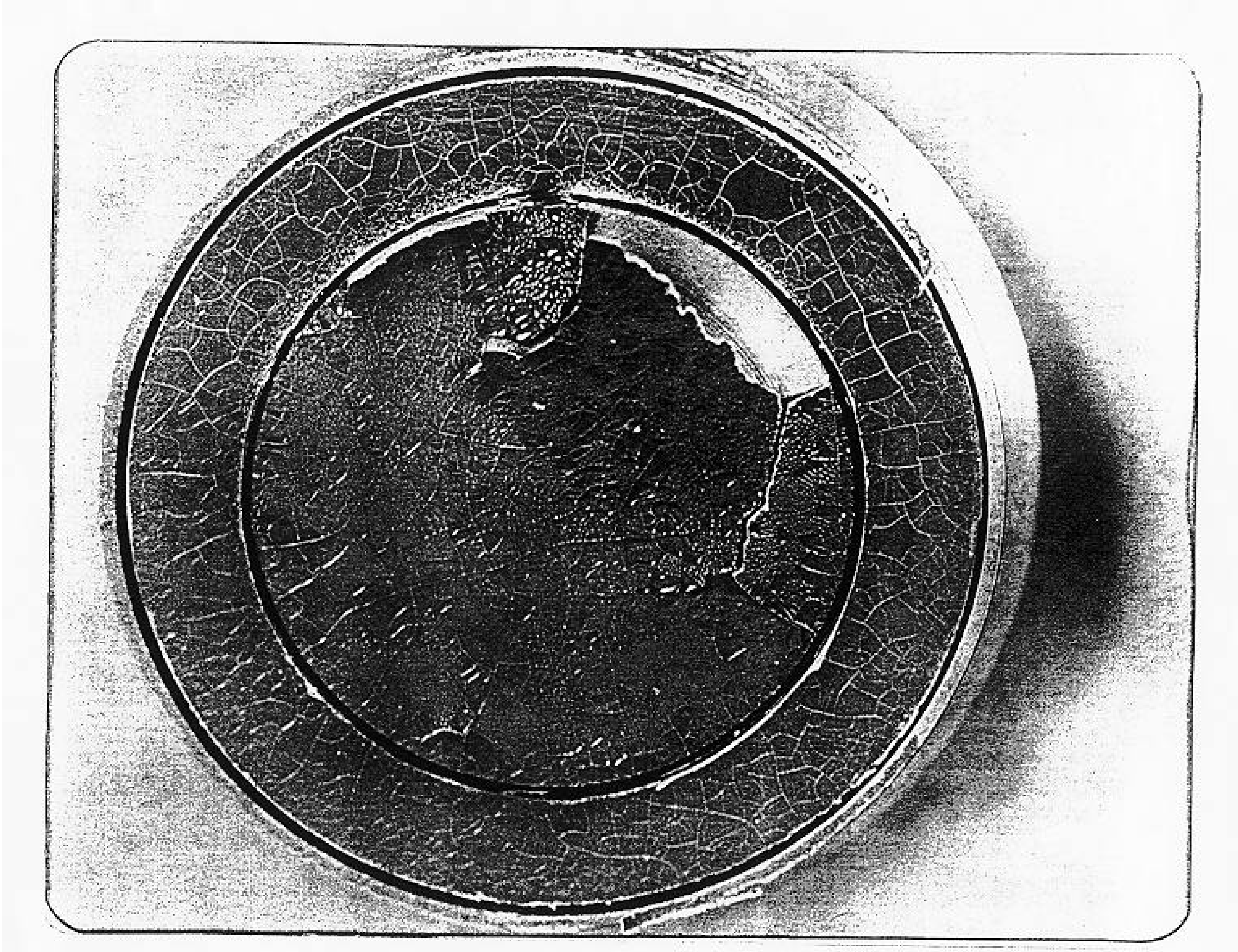


Post-flight 63X




20KV WD:18MM S:00000 P:00003
1MM

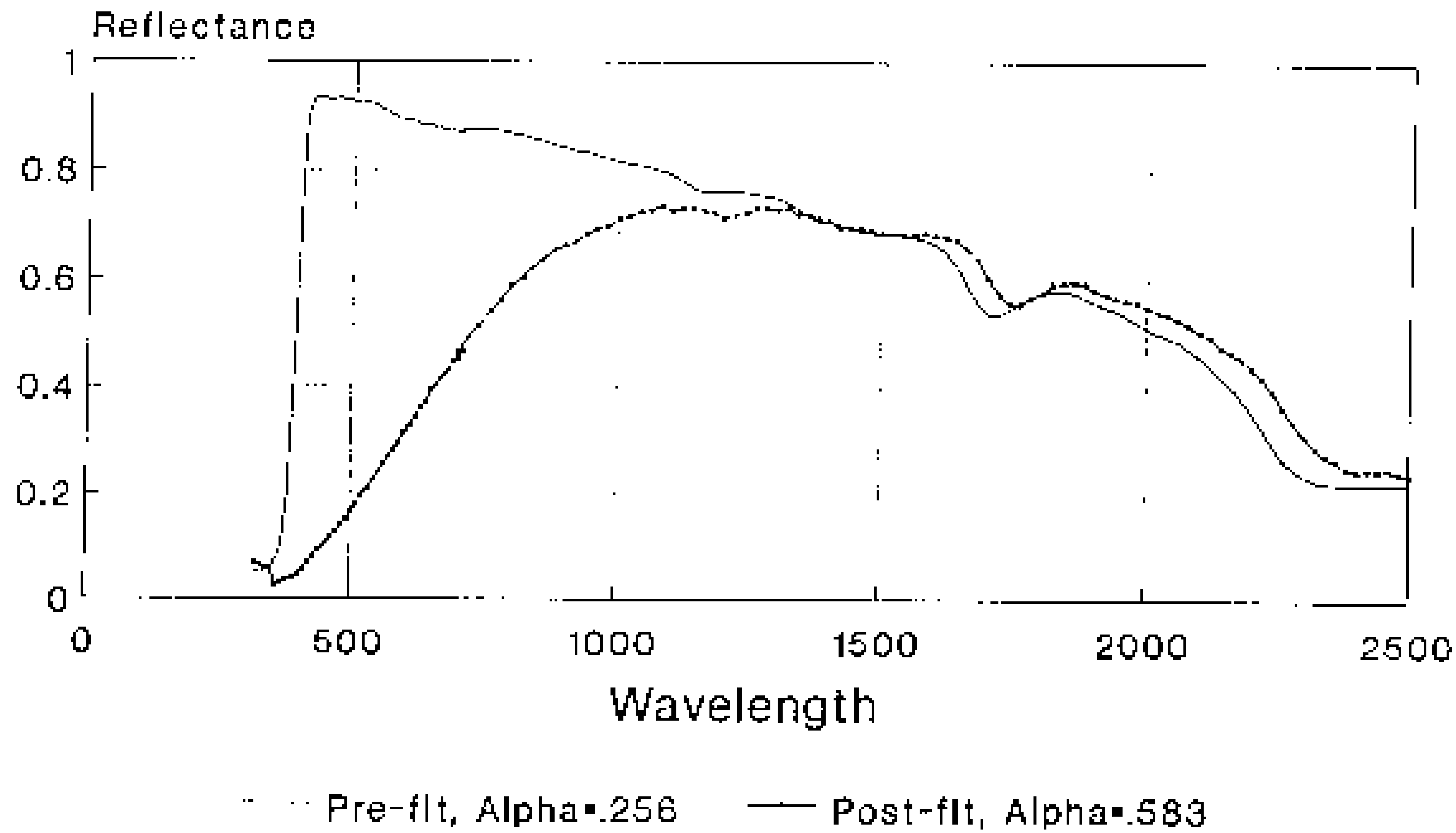

21.6X 20KV WD:18MM S:00000 P:00001
2MM



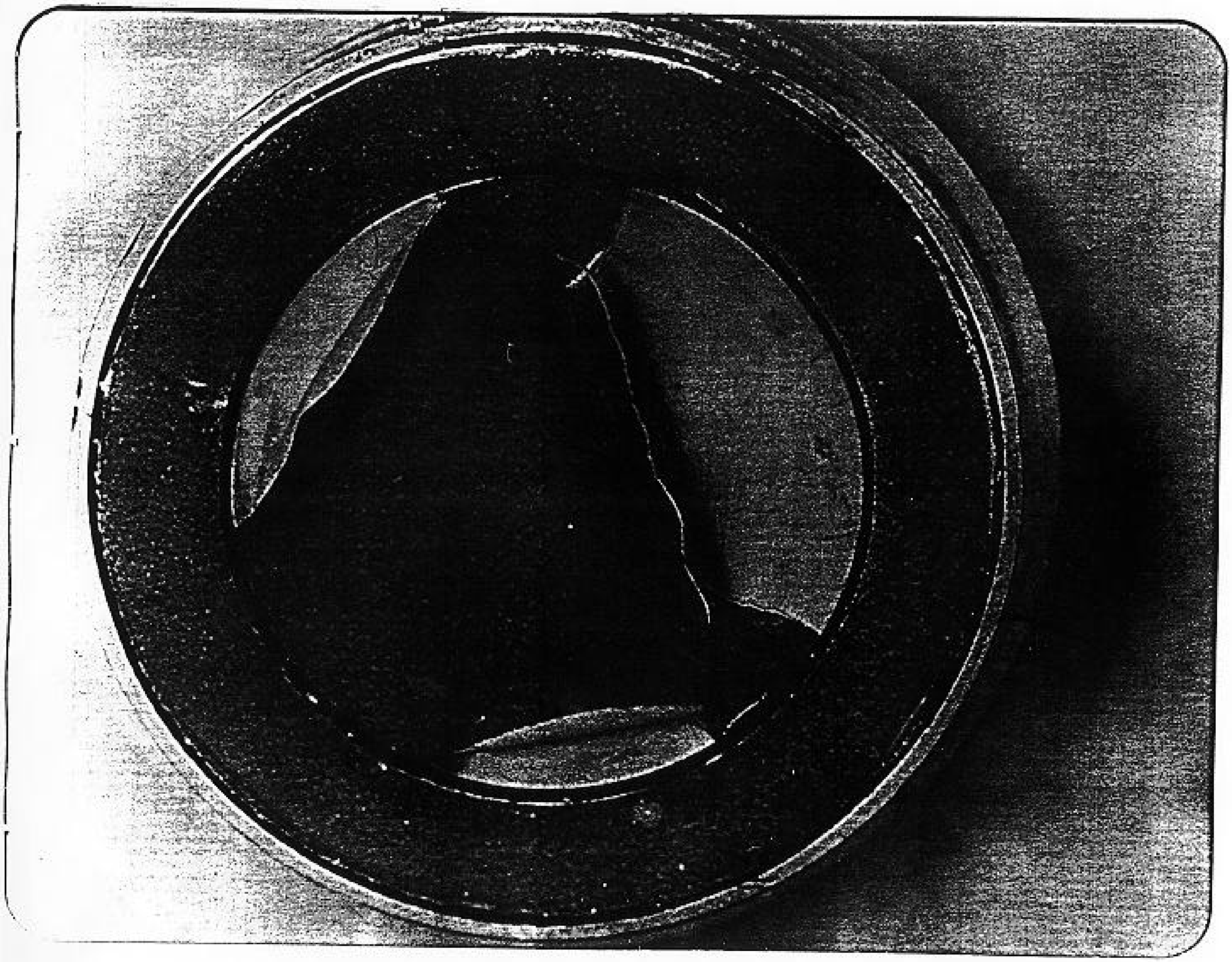
AZTek	Thermal Control Surfaces Experiment (TCSE) LDEF Experiment (S0069)	AZ Technology

TCSE Flight Sample Analysis

OI650 over A276 White Paint



drw115



SUMMARY

FEP ELONGATION DEGRADATION:

- Based on HST, LDEF and ground laboratory testing, none of the below environments acting alone appear sufficient to cause observed in-space degradation

  - Atomic oxygen
  - Mechanical stress from CTE mismatch
  - Electromagnetic radiation (visible through soft X-rays)
  - e^- & p^+
  - Steady state high temperature or low temperature
  - Thermal cycling

- Energetic e^- and/or p^+ exposure combined with thermal cycling may be the cause

- Demonstration of observed elongation reductions observed from HST samples must be performed in ground laboratories using representative HST fluences to:

  - Assure confidence in understanding degradation processes
  - Improve the reliability of FEP qualification testing

SUMMARY

HANDRAIL PAINT DEGRADATION:

- Browning and spalling due to combined effects of:
  - Atomic oxygen
  - UV radiation
  - Thermal cycling
- Probable degradation processes:
  - Atomic oxygen conversion of silicone to silica
  - Shrinkage and embrittlement of surface of oxidized silicone
  - Cracking of oxidized silicone surface
  - UV caused crosslinking, embrittlement and darkening of urethane binder
  - Thermal cycling caused stresses due to paint/aluminum CTE mismatch
  - Spalling of paint