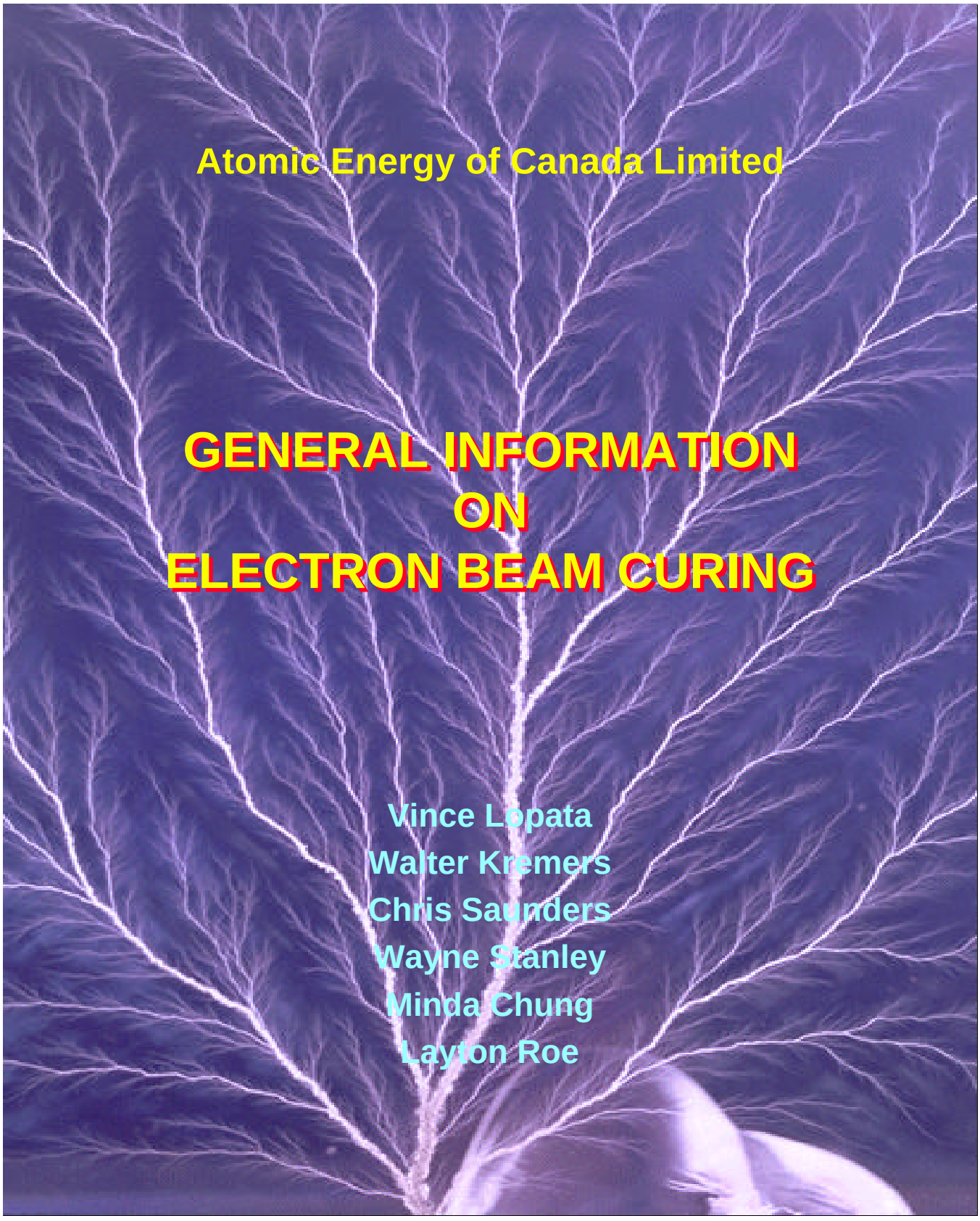
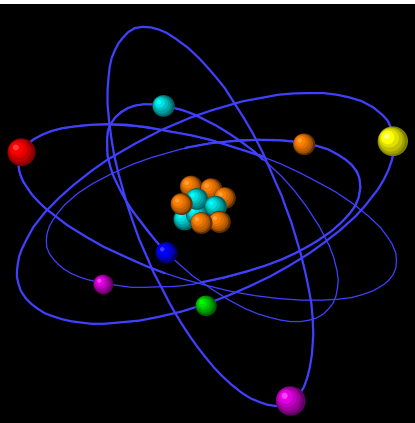


Atomic Energy of Canada Limited

GENERAL INFORMATION ON ELECTRON BEAM CURING

Vince Lopata
Walter Kremers
Chris Saunders
Wayne Stanley
Minda Chung
Layton Roe



GENERAL INFORMATION

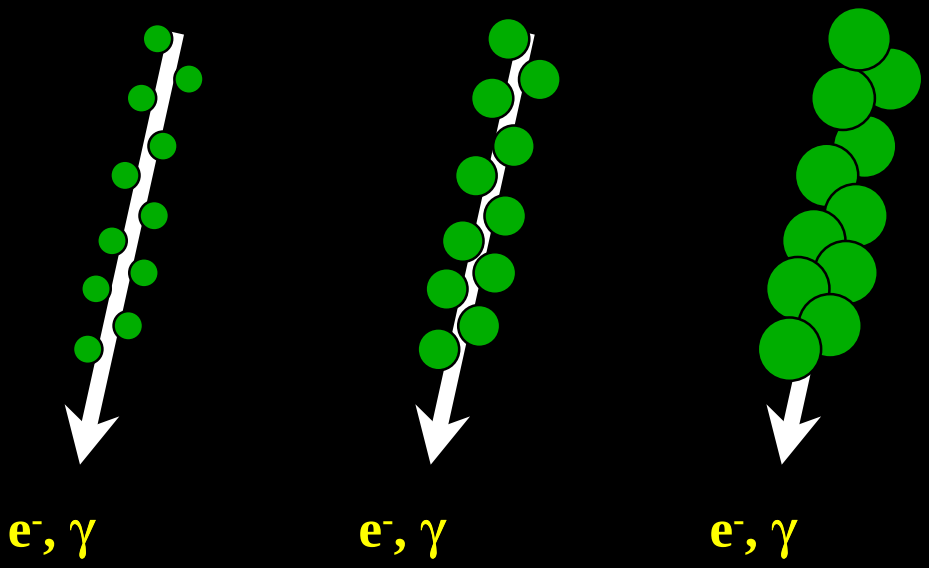
ON

RADIATION CHEMISTRY

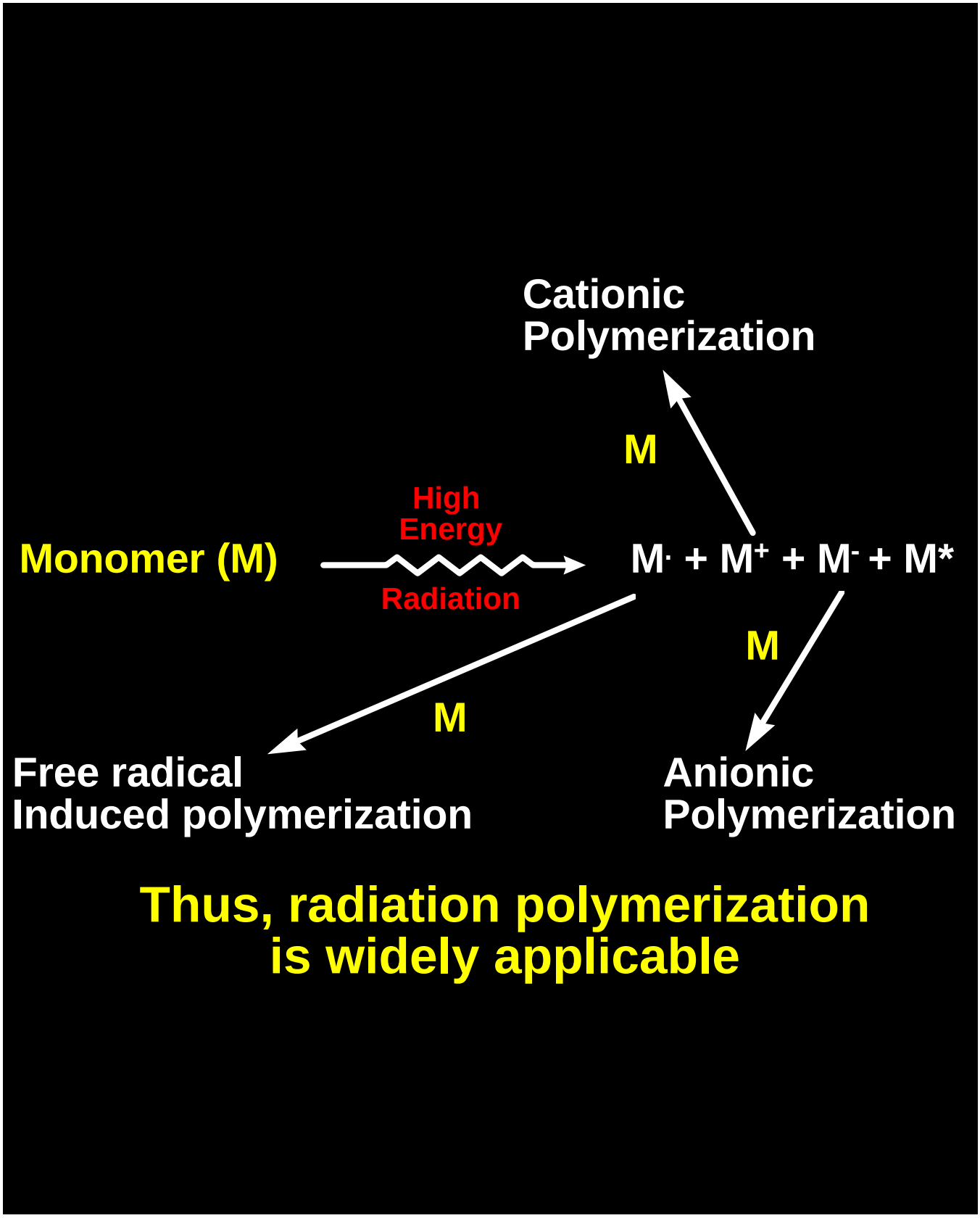
AND

PROCESSING

RADIATION POLYMERIZATION

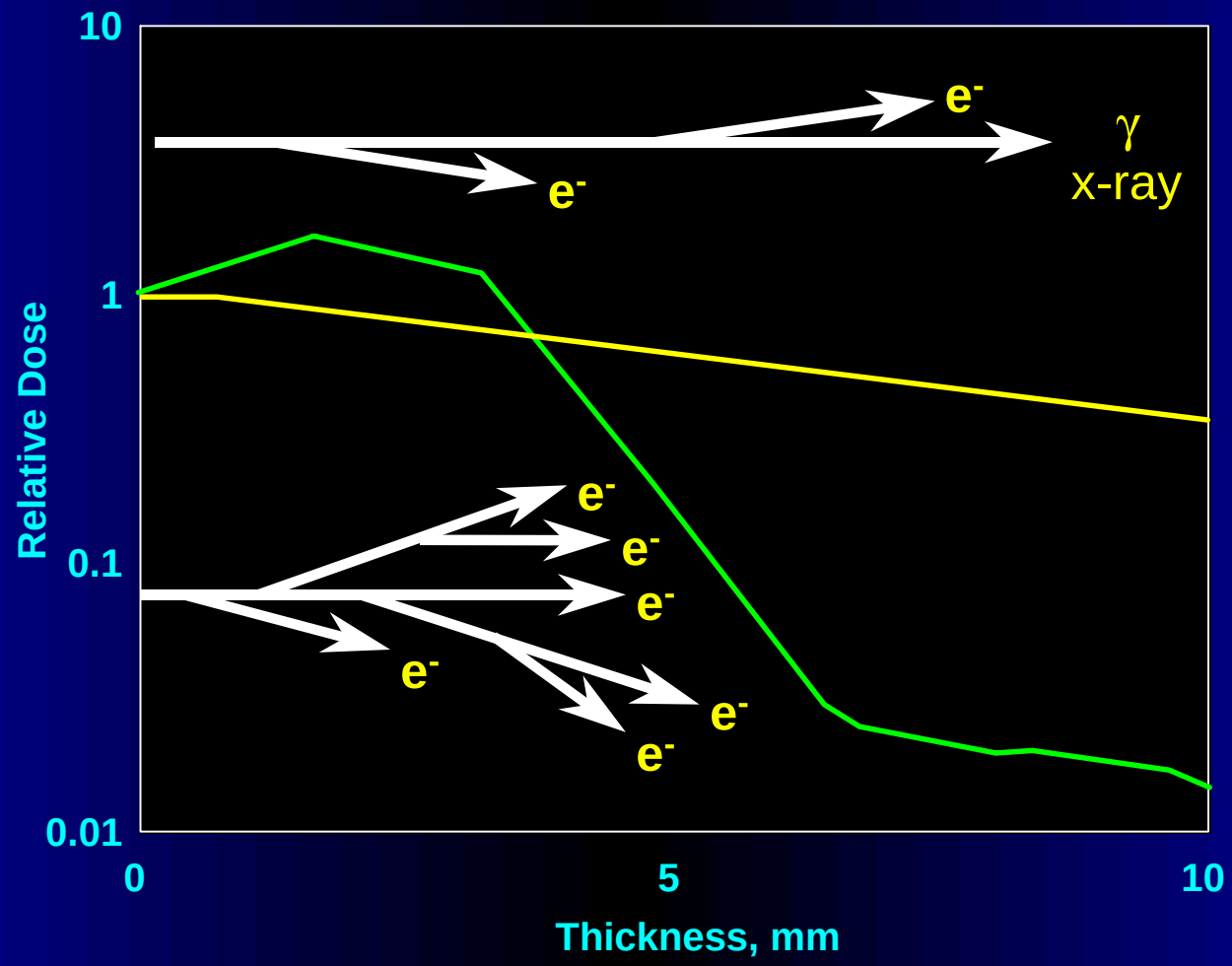


- Electron travels 1 cm of composite in 3×10^{-11} seconds
- It takes approximately 2 to 3 eV of energy to produce one active specie
- Along a 1 cm path an electron will produce approximately 8×10^{5} active spcies
- G value for polymerization: 20,000 to 30,000
- G value for active site on polymer: 0.4 to 0.6

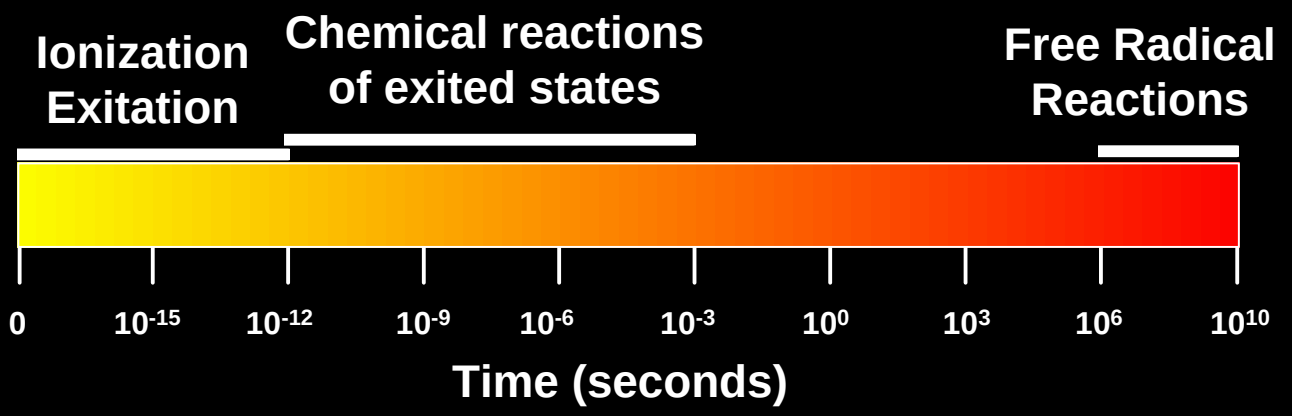


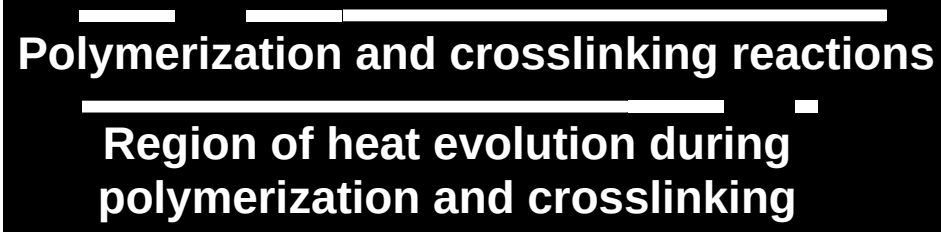
Thus, radiation polymerization is widely applicable

DOSE PROFILE AND PENETRATION OF ELECTRONS AND GAMMA RAYS

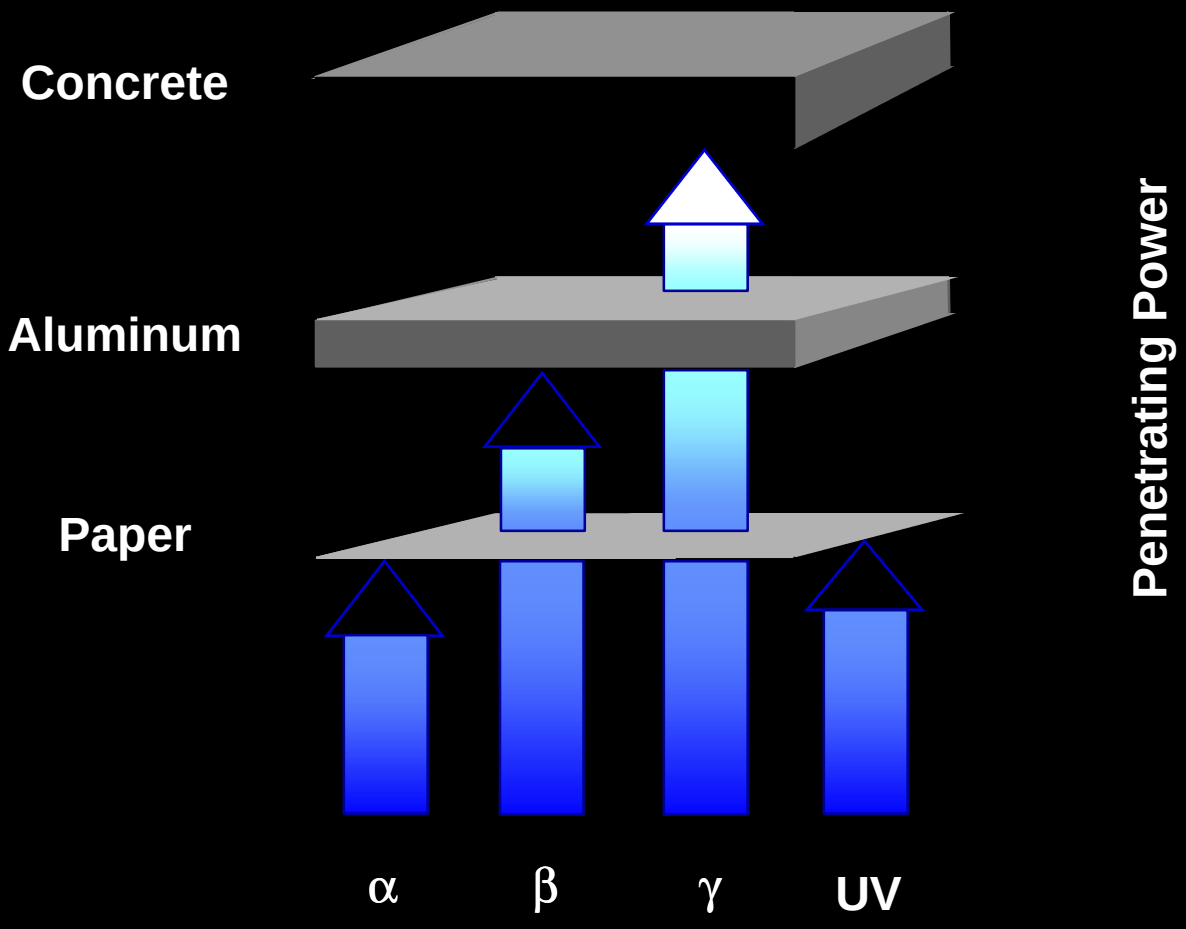


Time-Scale of Radiolytic Events in Polymers

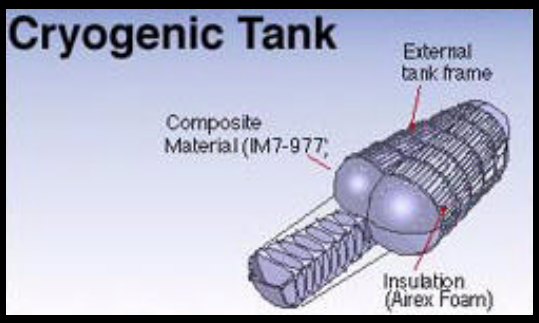




DIFFERENT PENETRATION OF VACUUM UV, α, β AND γ

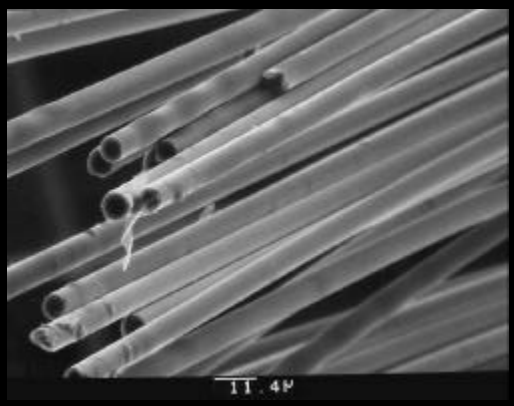


The difference in penetration is a result of different probabilities of interaction of α, β, γ and UV radiation with orbital electrons of a molecule

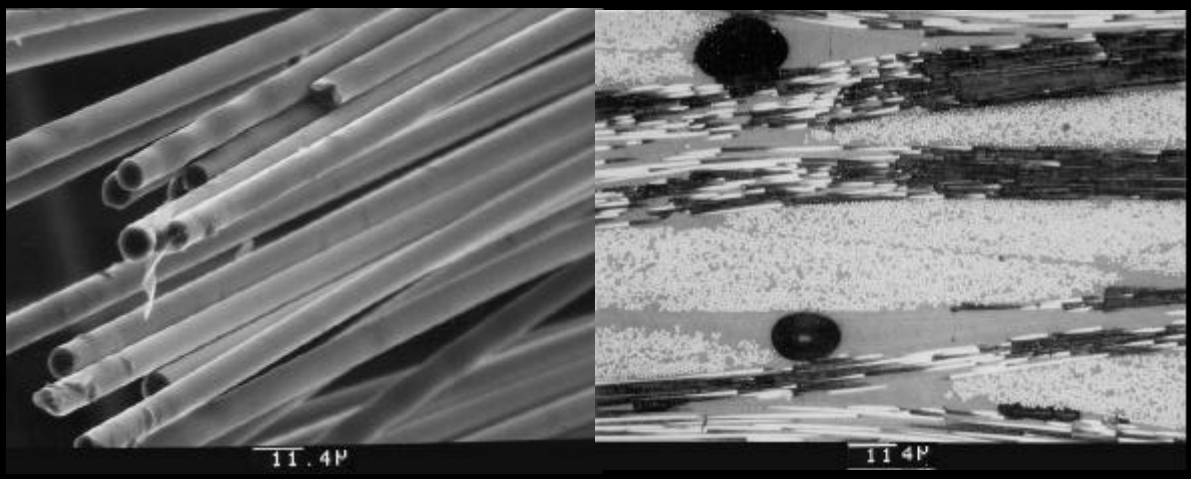


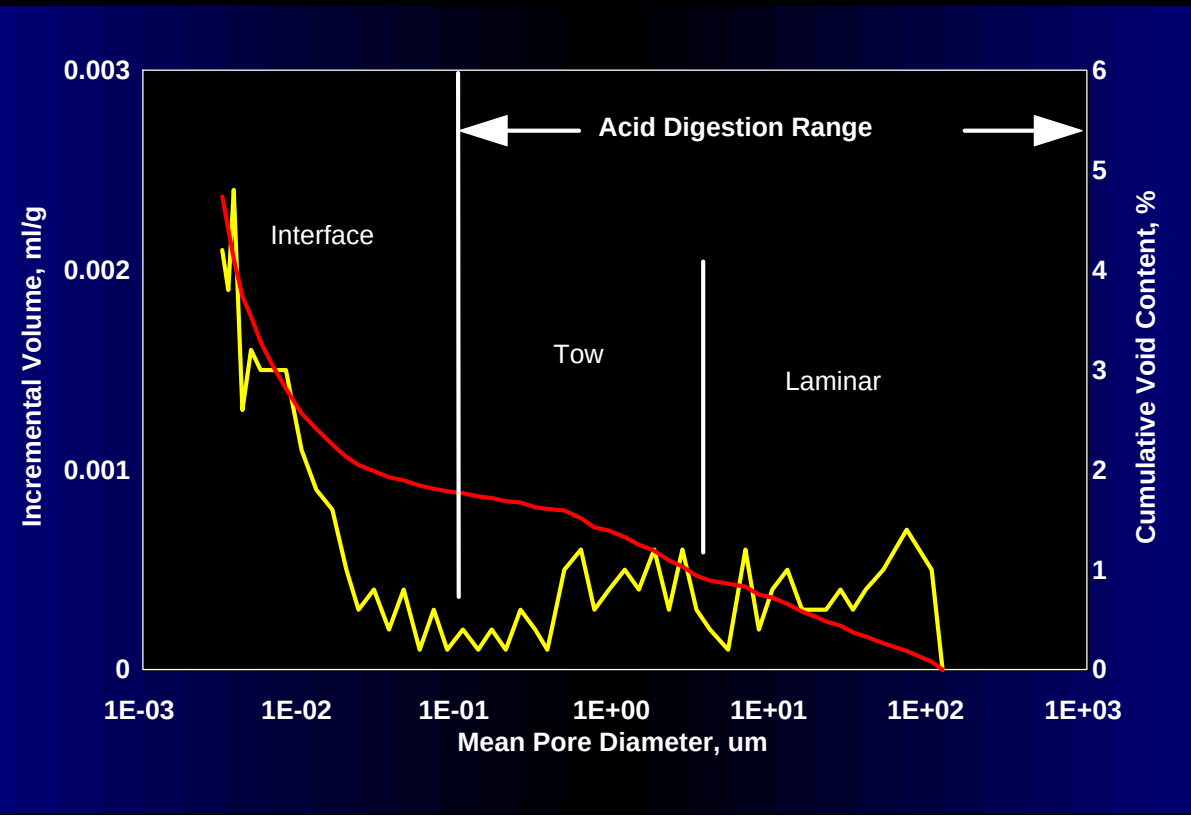
MICROCRACKING FROM THERMAL CYCLCING

INTERFACE

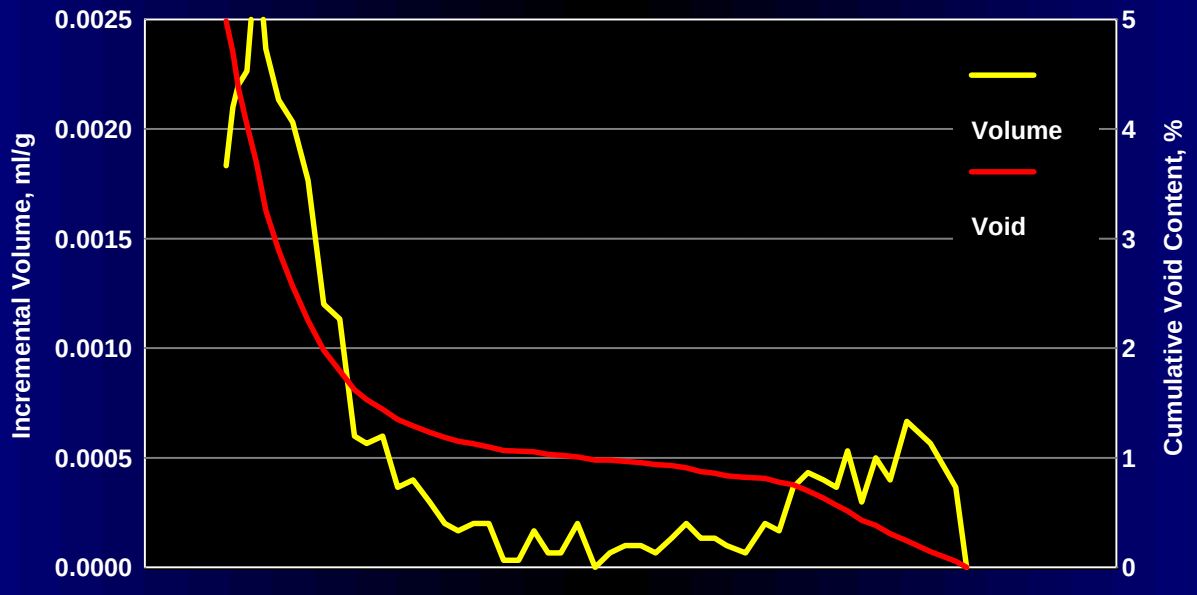


POROSITY DETERMINATION
TYPICAL MERCURY INTRUSION PLOT

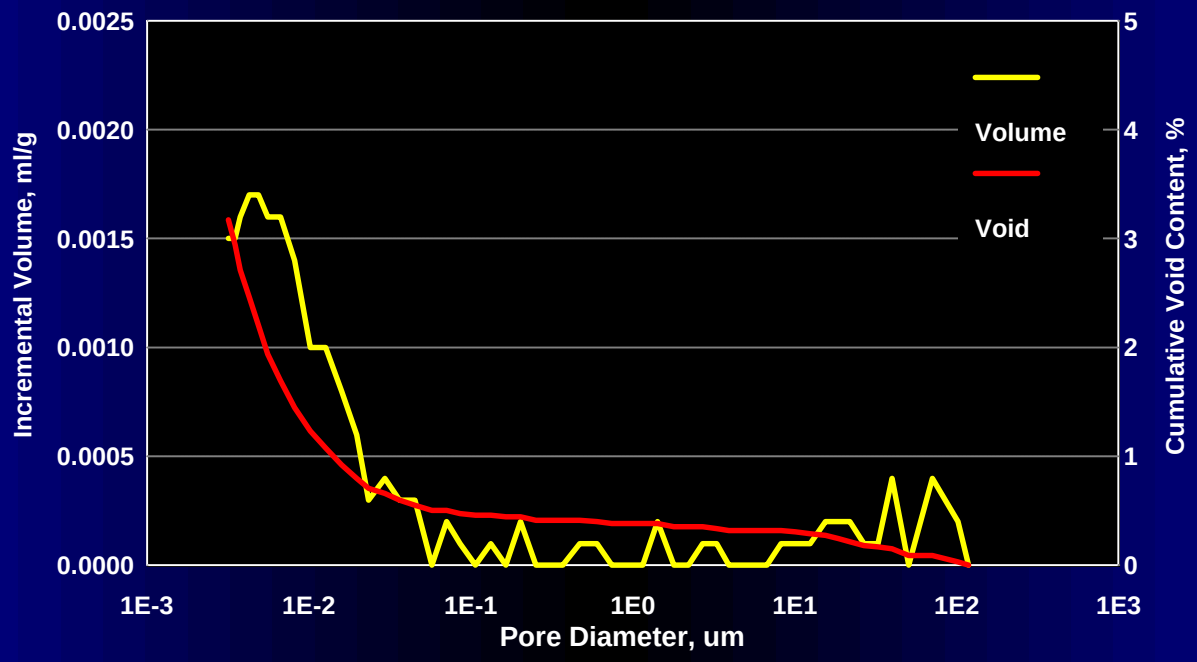


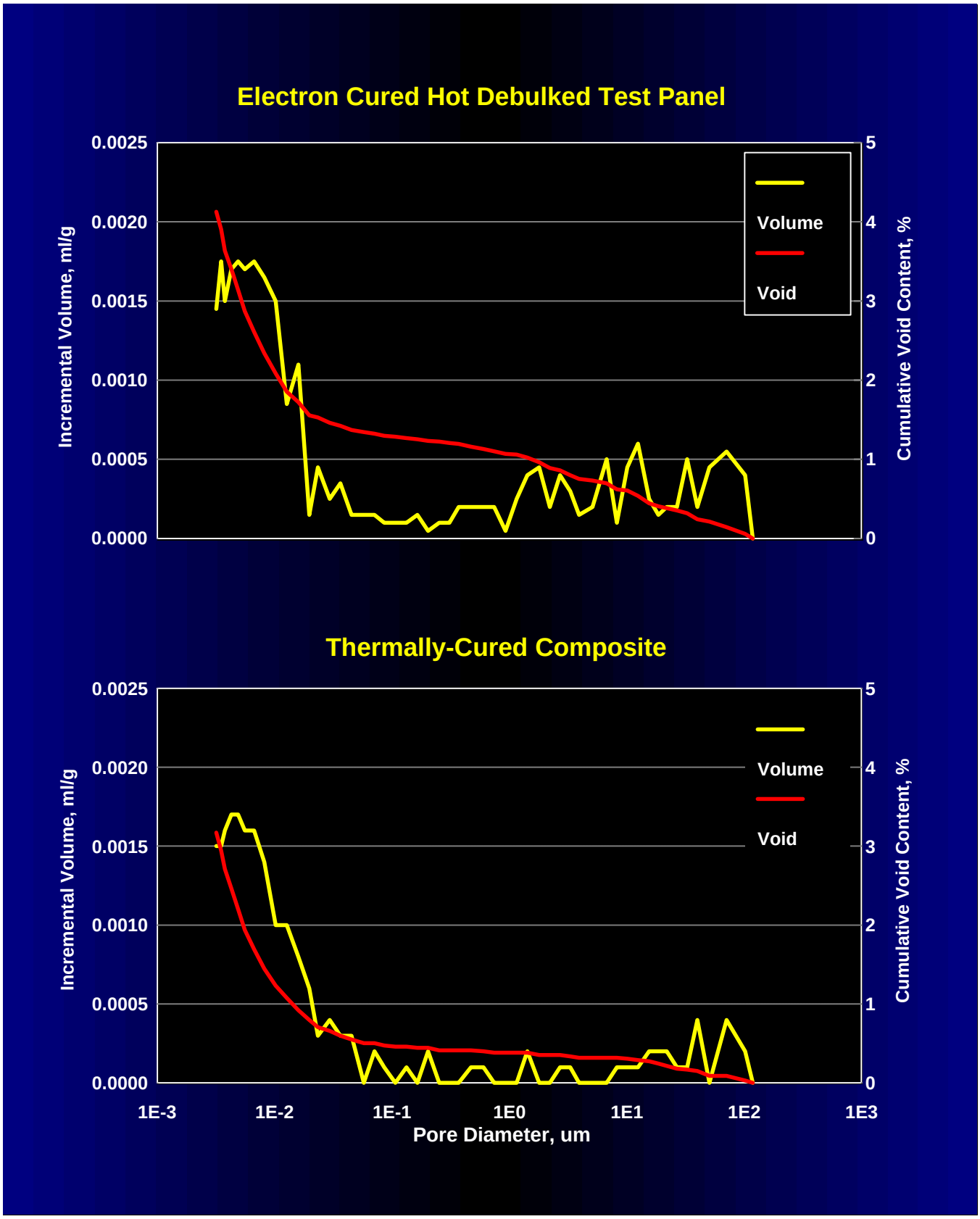


Electron Cured RTM Test Panel



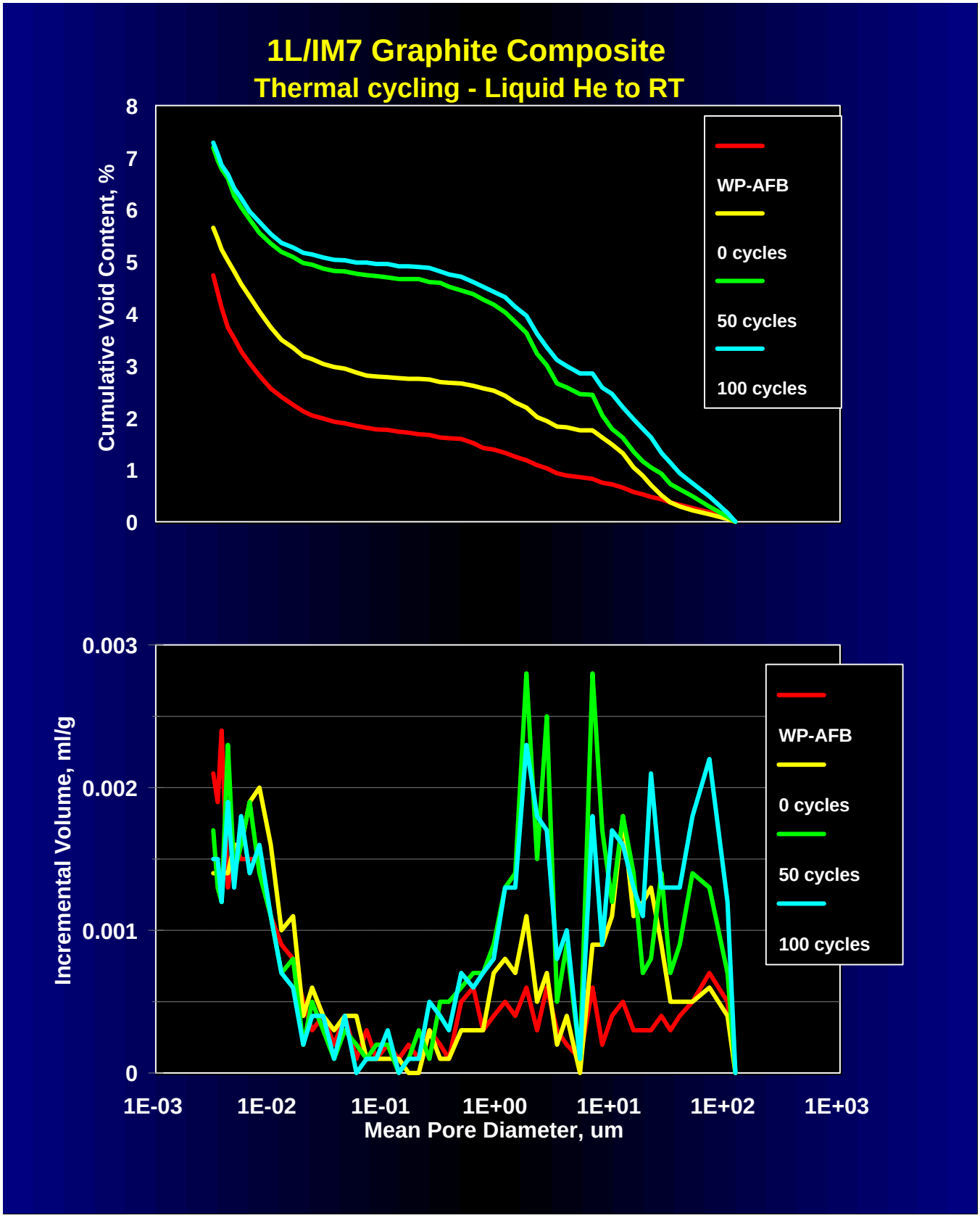
Thermally-Cured Composite

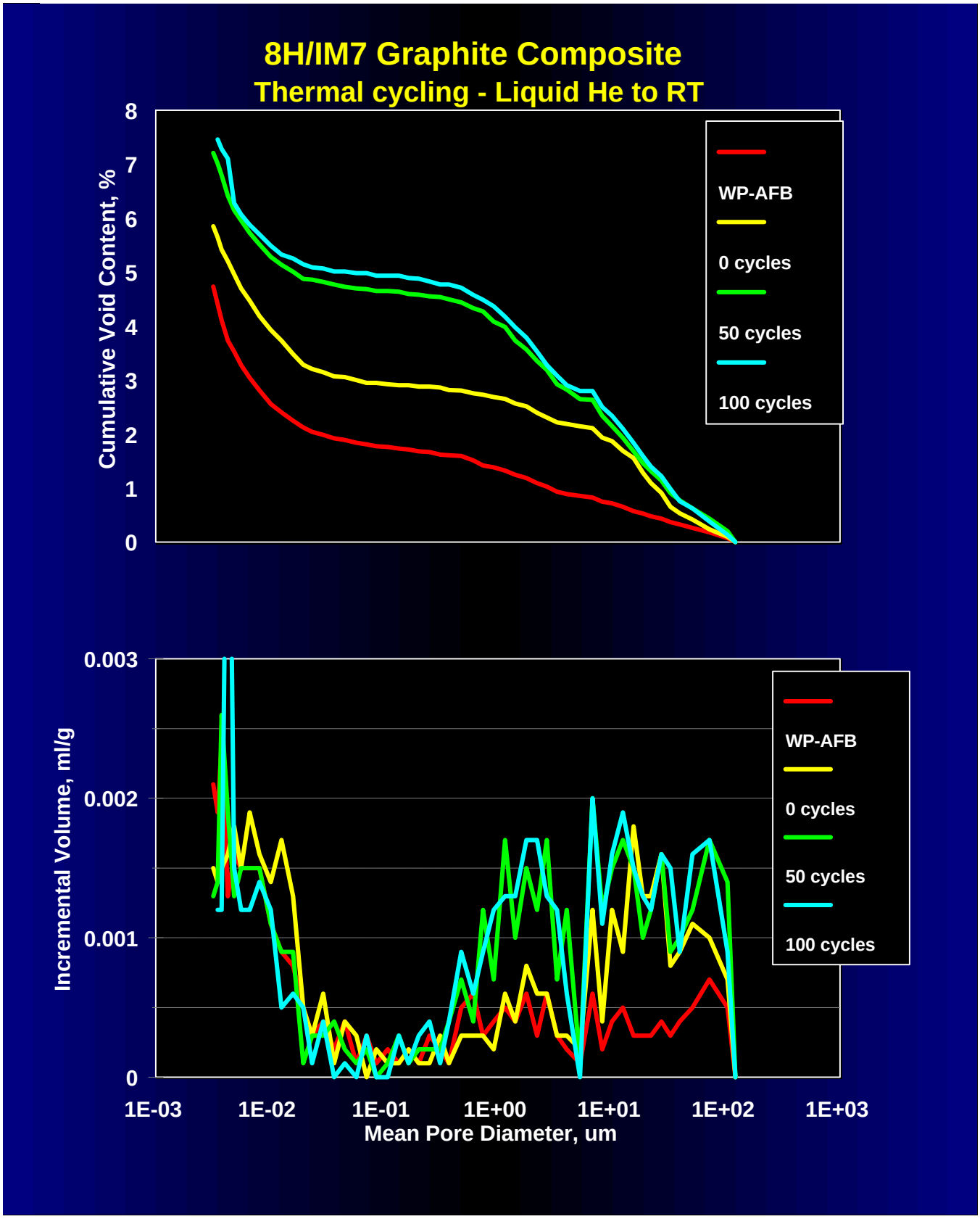


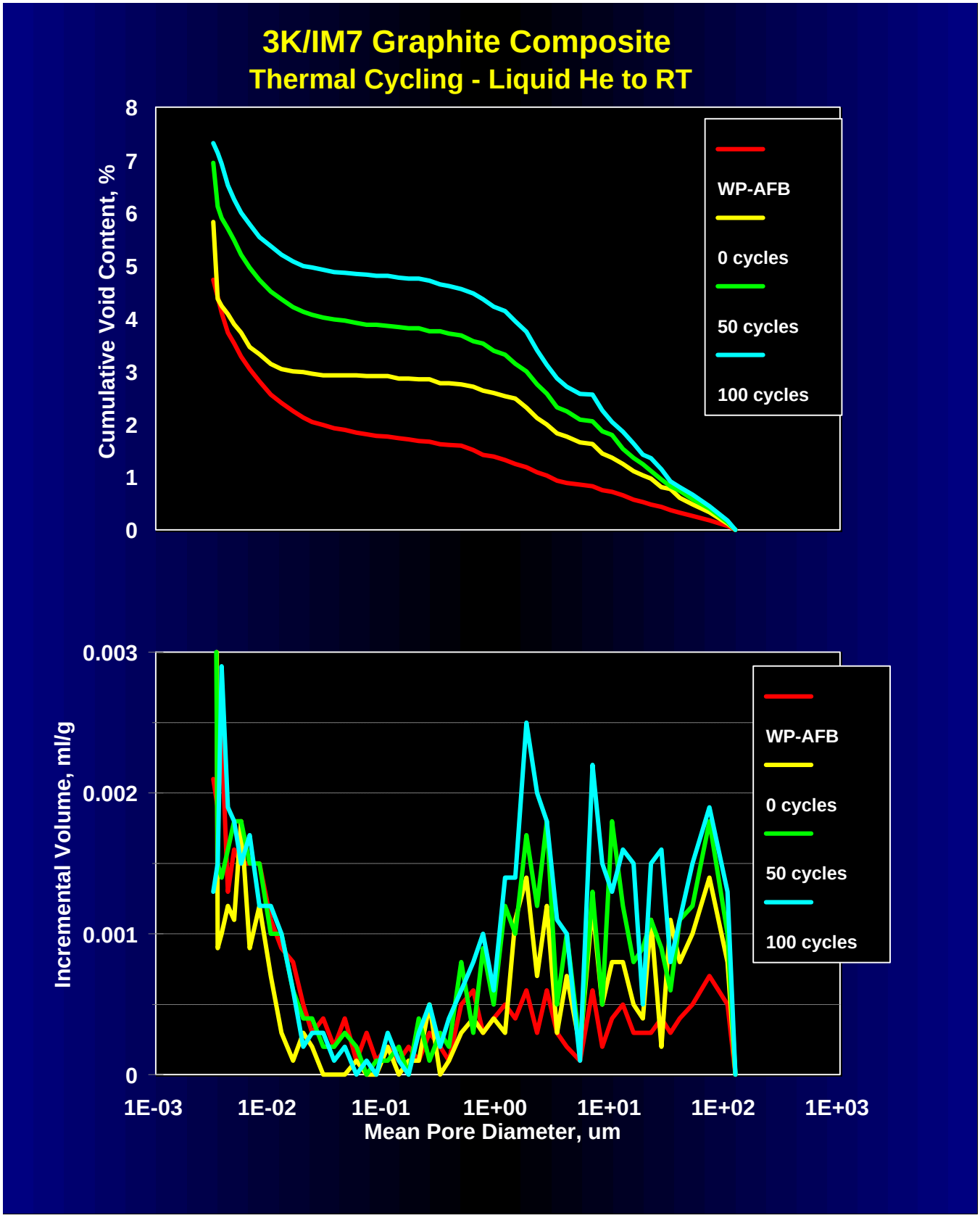

Electron Cured Hot Debulked Test Panel
Incremental Volume, ml/g
Cumulative Void Content, %
0.0025
0.0020
0.0015
0.0010
0.0005
0.0000
5
4
3
2
1
0
Volume
Void
Thermally-Cured Composite
Incremental Volume, ml/g
Cumulative Void Content, %
0.0025
0.0020
0.0015
0.0010
0.0005
0.0000
5
4
3
2
1
0
Volume
Void
1E-3
1E-2
1E-1
1E0
1E1
1E2
1E3
Pore Diameter, um

COMPARISON OF VOID CONTENT FOR VARIOUS REGIONS BY MODE OF MANUFACTURE

Region	Mode of Manufacture		
	Thermal Cured	EB RTM	Cured Hot Debulked
Interlaminar	0.34	0.86	0.80
Tow	0.12	0.27	0.49
Interface	2.71	3.86	2.84


1L/IM7 Graphite Composite
Thermal cycling - Liquid He to RT
Cumulative Void Content, %
8
7
6
5
4
3
2
1
0
WP-AFB
0 cycles
50 cycles
100 cycles
Incremental Volume, ml/g
0.003
0.002
0.001
0
1E-03
1E-02
1E-01
1E+00
1E+01
1E+02
1E+03
Mean Pore Diameter, um
WP-AFB
0 cycles
50 cycles
100 cycles


8H/IM7 Graphite Composite
Thermal cycling - Liquid He to RT
Cumulative Void Content, %
0
1
2
3
4
5
6
7
8
WP-AFB
0 cycles
50 cycles
100 cycles
Incremental Volume, ml/g
0
0.001
0.002
0.003
1E-03
1E-02
1E-01
1E+00
1E+01
1E+02
1E+03
Mean Pore Diameter, um
WP-AFB
0 cycles
50 cycles
100 cycles


3K/IM7 Graphite Composite
Thermal Cycling - Liquid He to RT
Cumulative Void Content, %
8
7
6
5
4
3
2
1
0
WP-AFB
0 cycles
50 cycles
100 cycles
Incremental Volume, ml/g
0.003
0.002
0.001
0
1E-03
1E-02
1E-01
1E+00
1E+01
1E+02
1E+03
Mean Pore Diameter, um
WP-AFB
0 cycles
50 cycles
100 cycles

COMPARISON OF THERMAL CYCLING OF EB-CURED GRAPHITE COMPOSITES

Graphite Fiber: 1M7 unidirection tape
Layup: $(0,90)_2(90,0)_2$
Thermal Cycle: -270 to 25°C

Resin System	Void Region	Void Content, %			Ratio of Increase	
		0	50	100	50	100
1L	Interlaminar	1.85	2.66	3.10	0.44	0.67
	Tow	0.92	2.05	1.86	1.24	1.03
	Interface	2.87	2.52	2.35	-0.12	-0.18
3K	Interlaminar	1.80	2.31	2.87	0.28	0.59
	Tow	1.08	1.55	1.95	0.43	0.80
	Interface	2.94	3.08	2.49	0.04	-0.15
8H	Interlaminar	2.25	2.91	3.07	0.30	0.37
	Tow	0.77	1.70	1.87	1.22	1.44
	Interface	2.94	2.56	2.52	-0.13	-0.14
Thermal Cure	Interlaminar	0.94				
	Tow	0.84				
	Interface	2.96				

TOOLING MATERIALS

AND

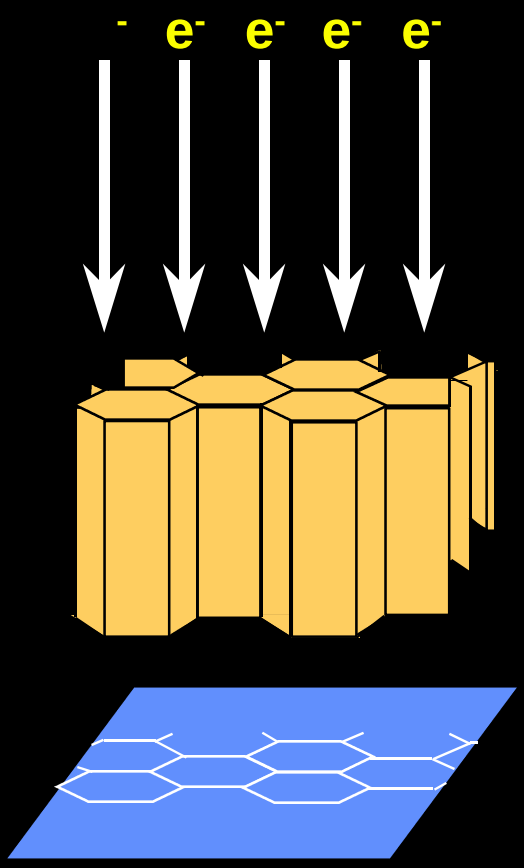
ELECTRON PENETRATION

EXPERIMENTAL SETUP
ELECTRON PENETRATION
OF TOOLING MATERIAL

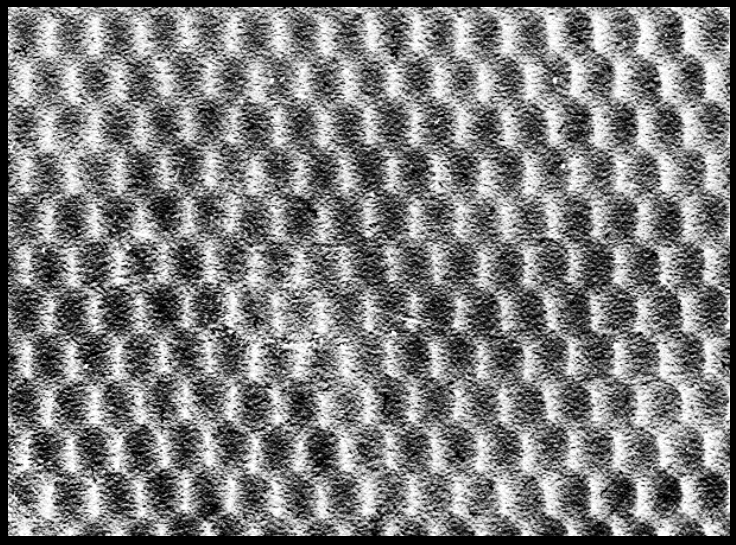
Electron Beam

Tooling Material

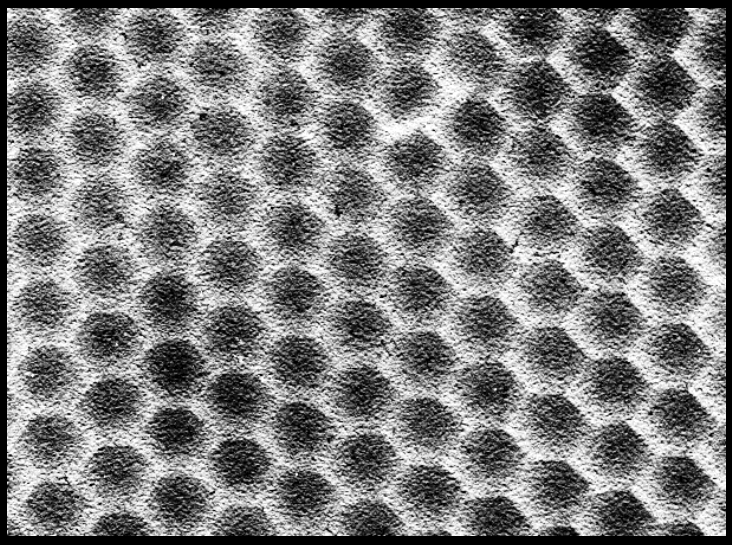
Radiation Sensitive Film



Honeycomb Structures

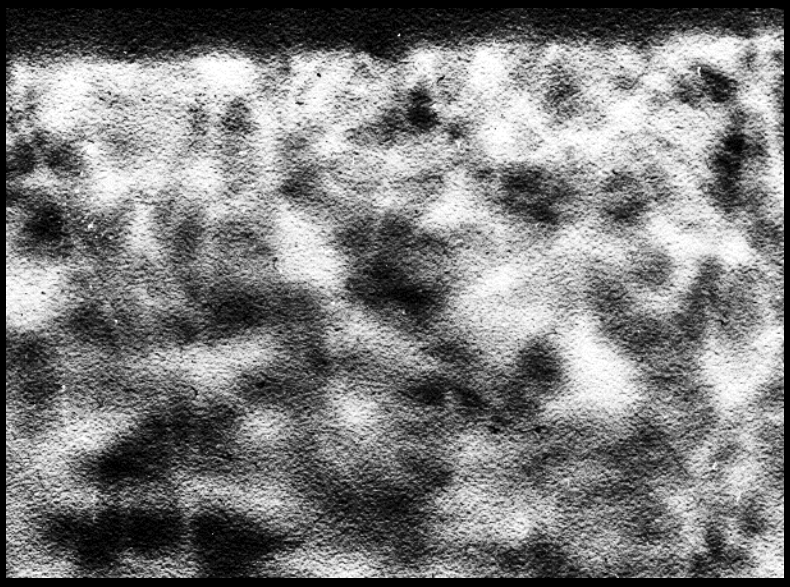


Nomex, 1 inch thick, 1/8 inch cell

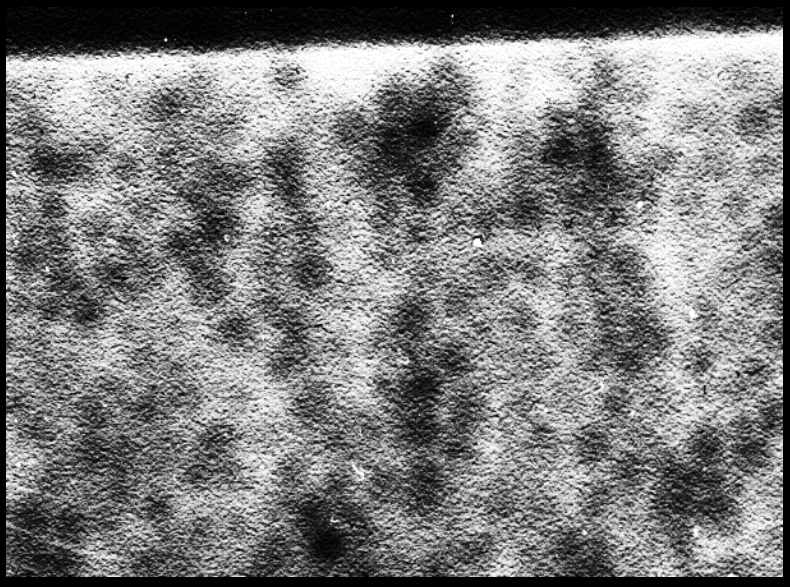


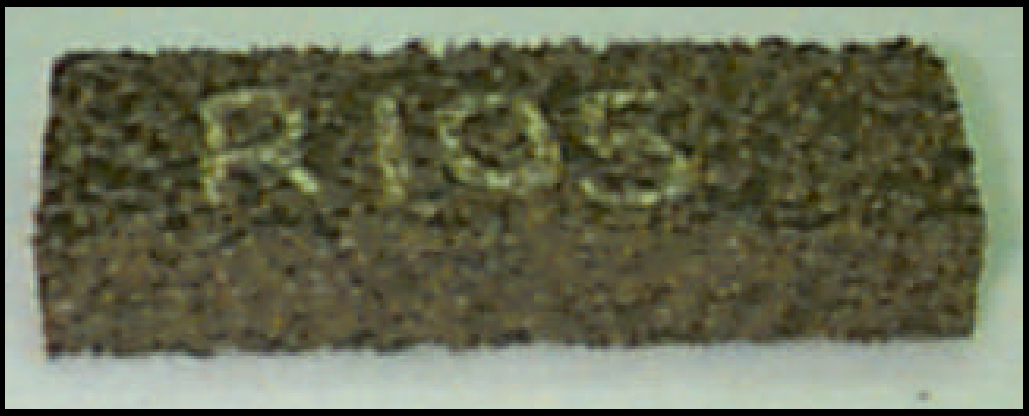
Aluminum, 1 inch thick, 3/16 inch cell

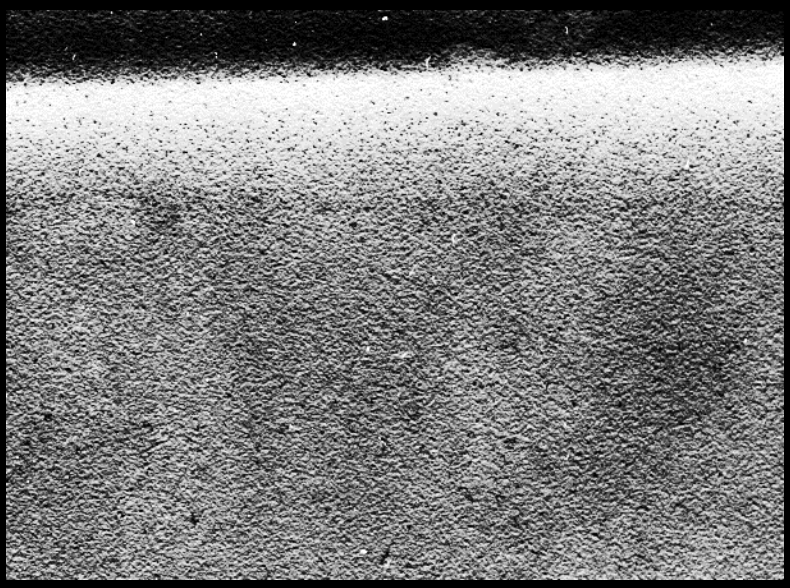
BIRD'S NEST TYPE STRUCTURE



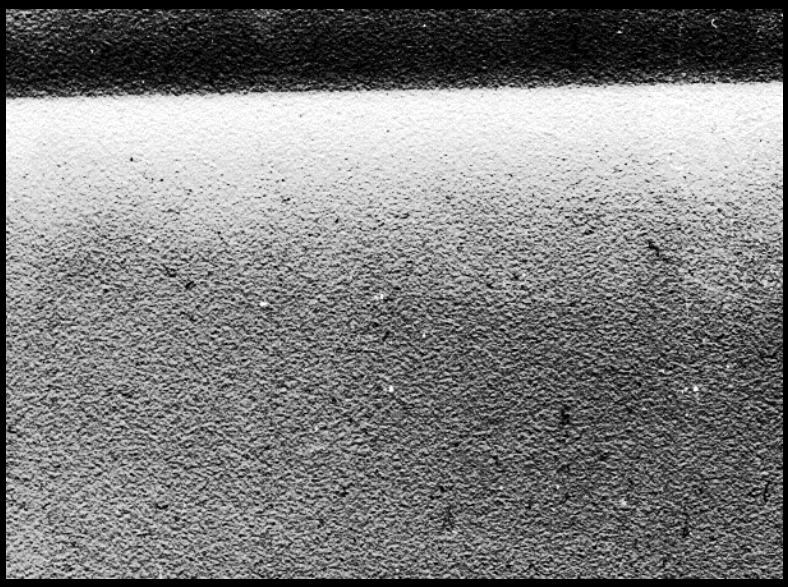
HOLLOW CERAMIC SPHERES







CERAMIC MICROSPHERES



FOAM