Fermi National Accelerator Laboratory

FERMILAB-TM-1875

Summary of the Radiation Damage Studies of the SDC Dopants in Polystyrene

A. Pla-Dalmau, G.W. Foster and G. Zhang

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P.O. Box 500, Batavia, Illinois 60510

December 1993

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DODCI 69
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DQOCI 71
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Introduction

Approximately 80 commercially available fluorescent organic compounds were studied as dopants in a polystyrene matrix for possible use in wavelength shifting (WLS) fibers. The goal was to find a new green-emitting WLS fiber which would outperform in light yield and decay time the currently available fiber doped with K-27. Therefore the fluorescent compounds of interest should exhibit the following spectroscopic characteristics in polystyrene: λ_{abs}=400–450 nm, λ_{em}=450–550 nm, τ=3–7 ns (τ=12 ns for K-27), and quantum efficiency of minimum 0.7 (K-27 baseline). For further details on the range and properties of the compounds studied refer to "Final Results from the SDC Dopant Search for New Green Wavelength Shifting (WLS) Fibers", FERMILAB-TM-1873.

Polystyrene samples doped with different fluorescent compounds were prepared and characterized. Of all the compounds tested, only a series of coumarins exhibited the spectroscopic characteristics of interest. Radiation damage studies had to be performed on these samples in order to conclusively determine if they were better candidates than K-27 for green WLS fibers.

All samples except those showing opacity or deep coloration were irradiated. They were, however, separated in two sets. Radiation damage set No. 20 (RD20) was mainly formed by the coumarin derivatives. Radiation damage set No. 22 (RD22) was based on the remaining samples. The irradiations were performed at the Phoenix Memorial Laboratory (University of Michigan) using a ^{60}Co source. Both sets were exposed to a total dose of 10 Mrad in air, at a dose rate of 1.8 Mrad/h. Transmittance measurements were recorded before and after irradiation, and after annealing. After irradiation, the samples were annealed in oxygen to accelerate the recovery process. Although the samples were irradiated in air, they still underwent annealing in oxygen atmosphere because the dose rate had been high enough for the oxygen diffusion rate to be smaller than its consumption rate during irradiation. The final results are similar to those of an irradiation under inert atmosphere, with the exception of the formation of oxidation products on the surface of the samples.

Transmittance spectra were recorded with a Hewlett-Packard model 8451A diode array spectrophotometer. All transmittance measurements used undoped and unirradiated polystyrene as the reference. The transmittance

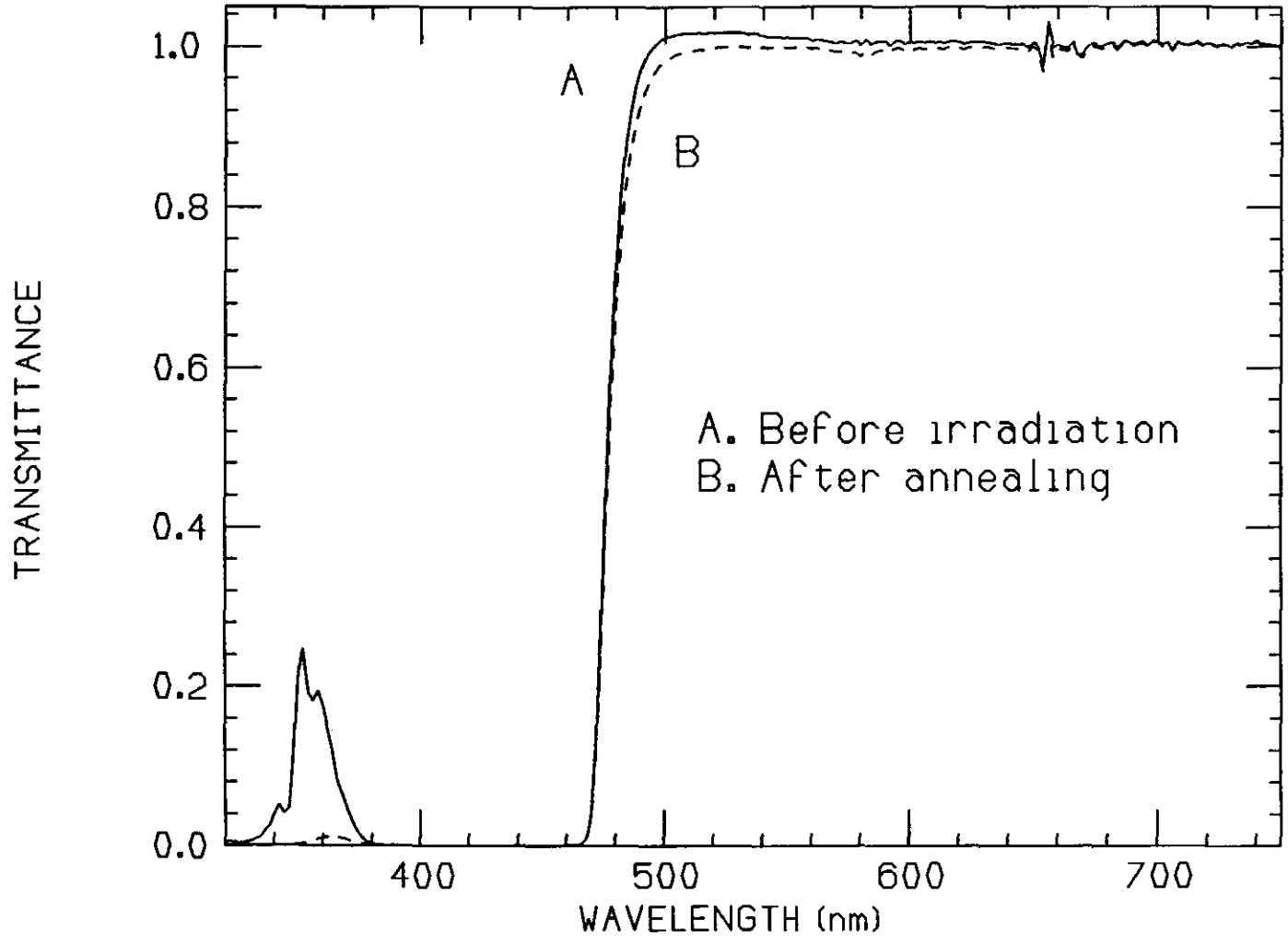
plots presented here observe the formal separation of the two sets, RD20 and RD22. The data for RD20 has been arranged in two plots for each dopant. The first plot shows the transmittance spectra before irradiation and after annealing. The second plot includes the transmittance spectra before irradiation plus two transmittance spectra recorded while the sample was annealing. For RD22, the data is shown in one single plot containing three measurements: one before irradiation, one after irradiation, and one after annealing in oxygen.

The RD20 data indicates that the performance under irradiation of the coumarins is significantly inferior to that of K-27. The losses in transmission of the coumarins are larger than those of K-27.

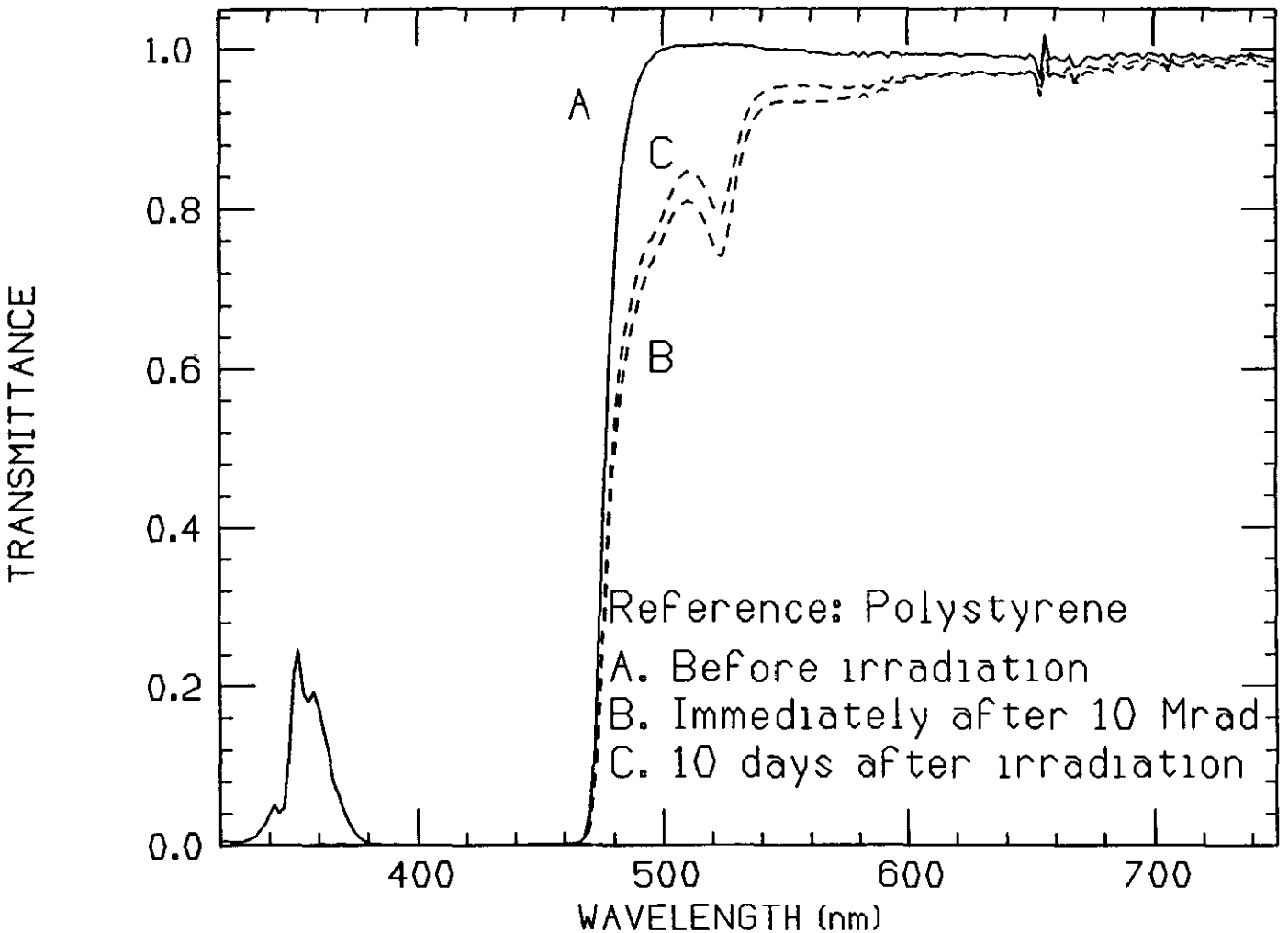
We wish to thank R. Blackburn of the Phoenix Memorial Laboratory of the University of Michigan for performing all sample irradiations. We wish to extend our appreciation to the members of the Particle Detector Group; in particular, Monica Szelag who plotted and organized the data presented in this document.

PART I
RADIATION DAMAGE SET #20

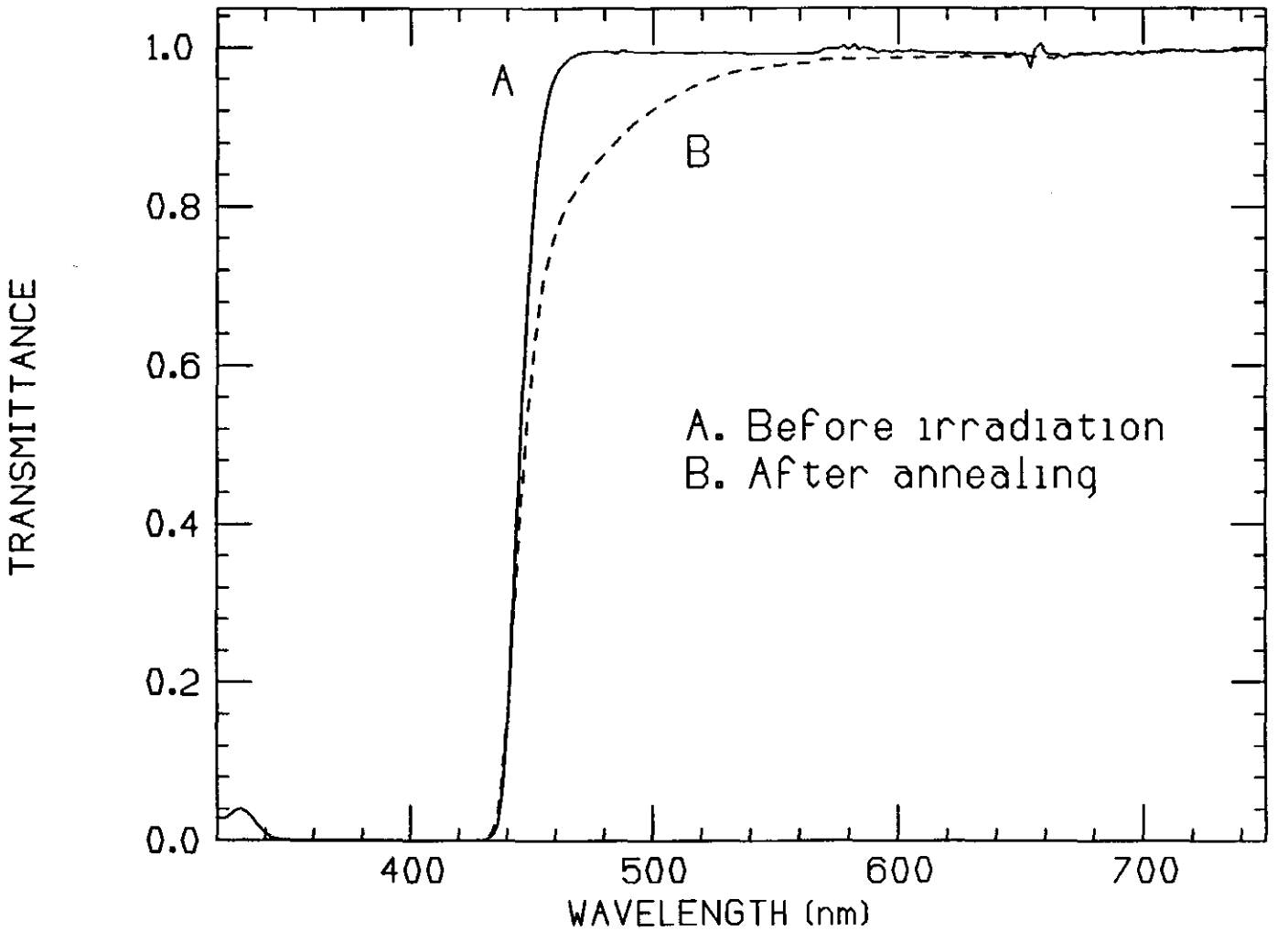
0.02% K27 - HIGH DOSE RATE IRRADIATION IN AIR

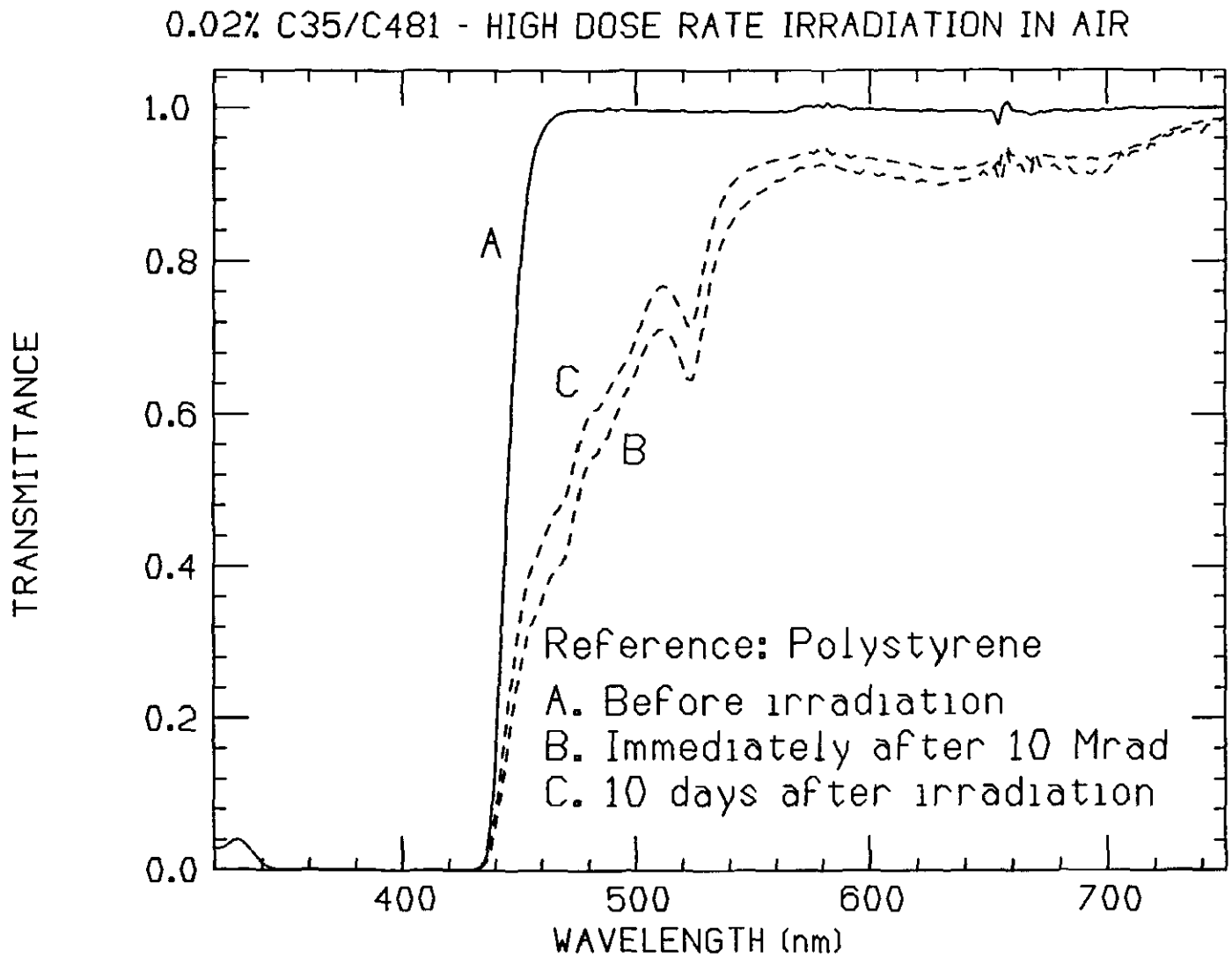


0.02% K27 - HIGH DOSE RATE IRRADIATION IN AIR

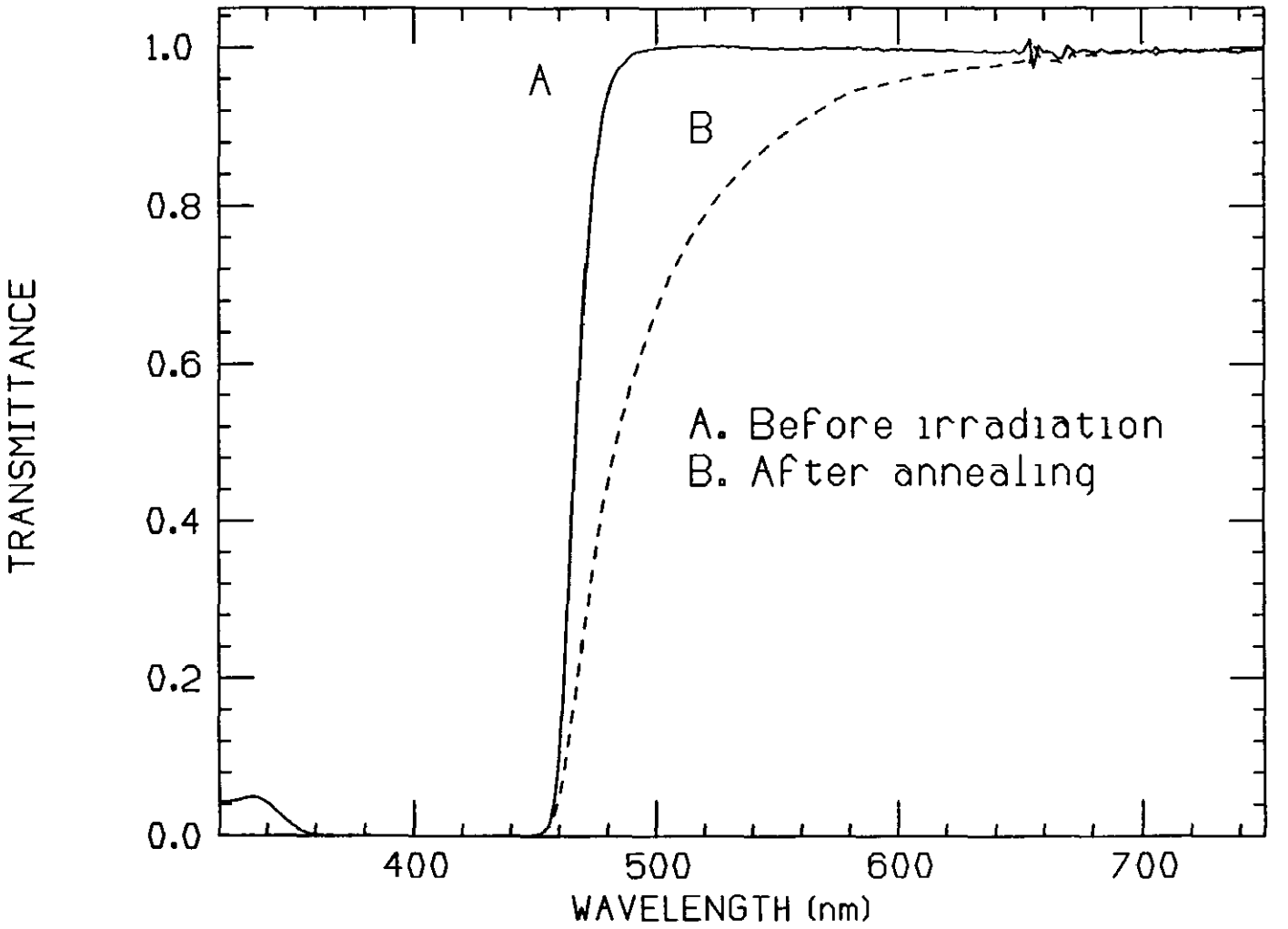


0.02% C35/C481 - HIGH DOSE RATE IRRADIATION IN AIR




0.02% C35/C481 - HIGH DOSE RATE IRRADIATION IN AIR
TRANSMITTANCE
1.0
0.8
0.6
0.4
0.2
0.0
400
500
600
700
WAVELENGTH (nm)
A
B
C
Reference: Polystyrene
A. Before irradiation
B. Immediately after 10 Mrad
C. 10 days after irradiation

0.02% C153 - HIGH DOSE RATE IRRADIATION IN AIR



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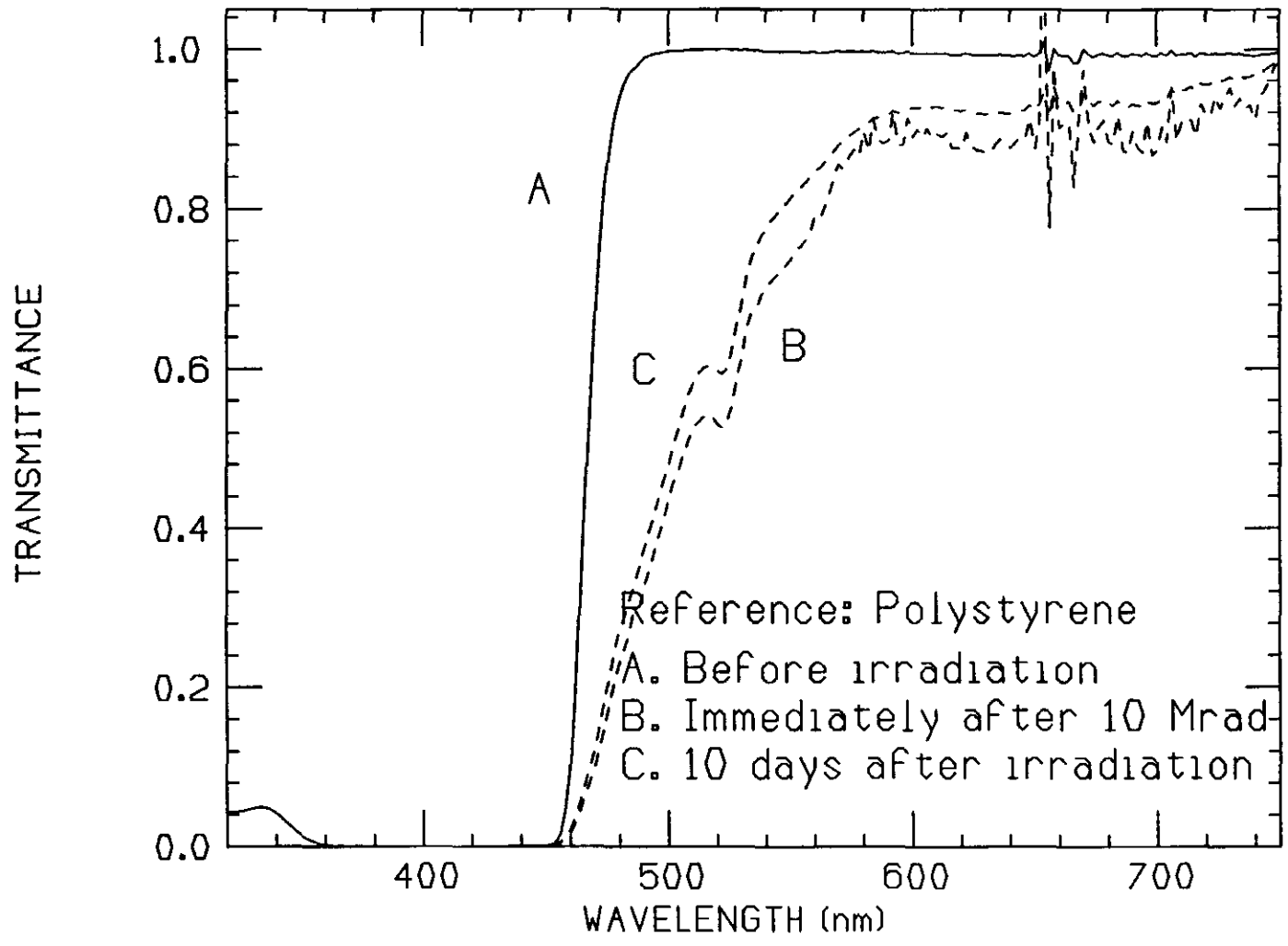

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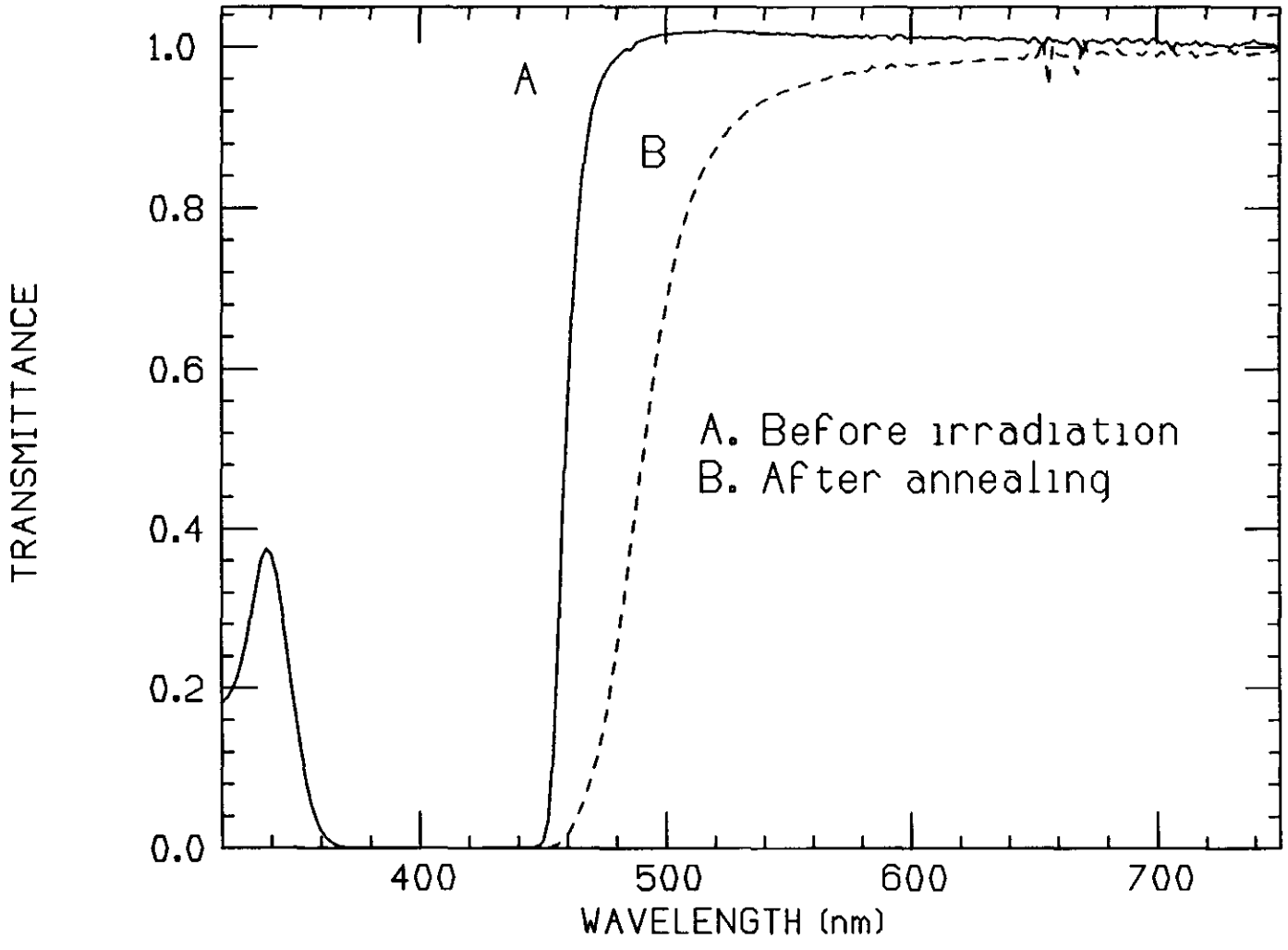
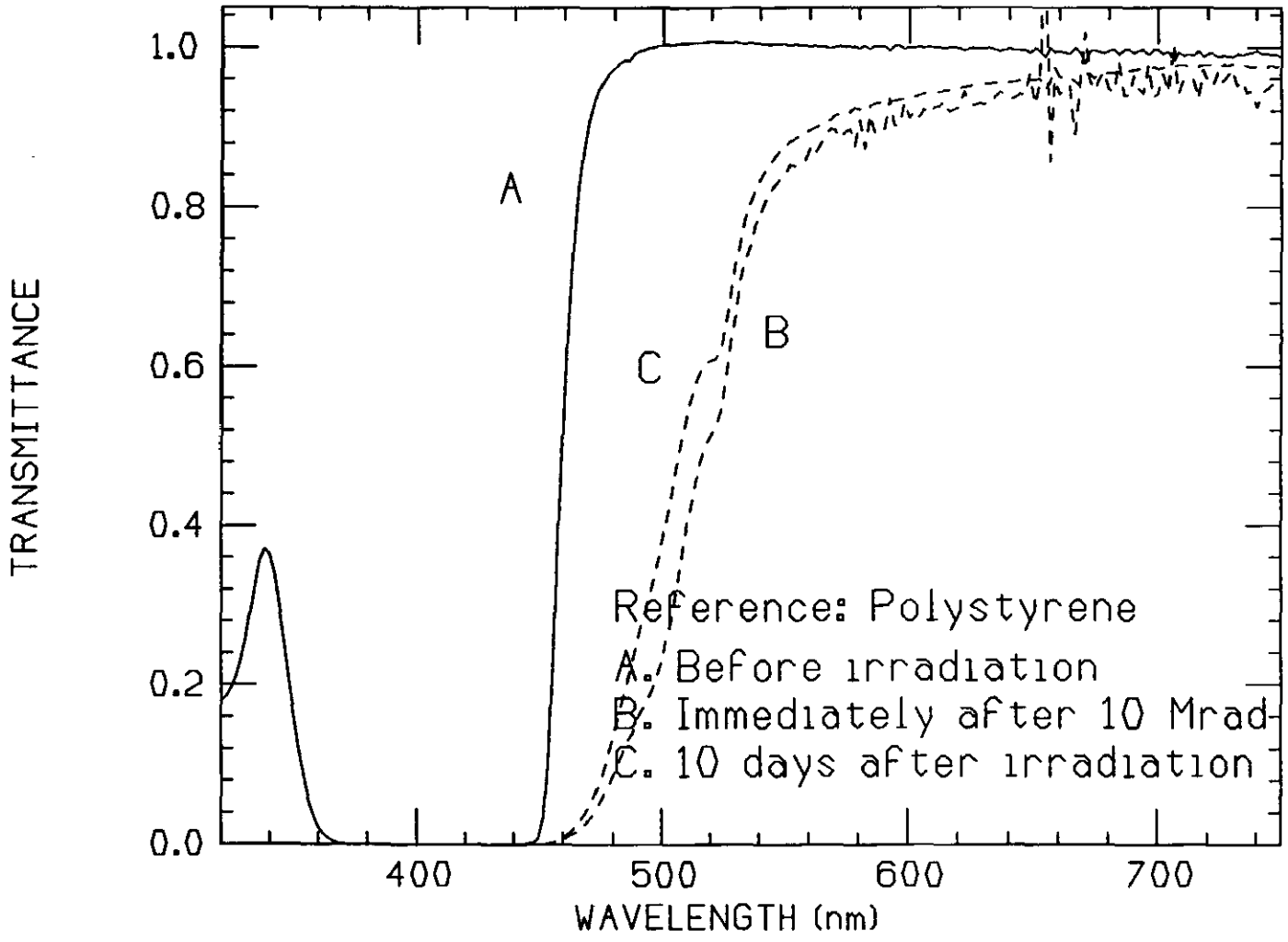
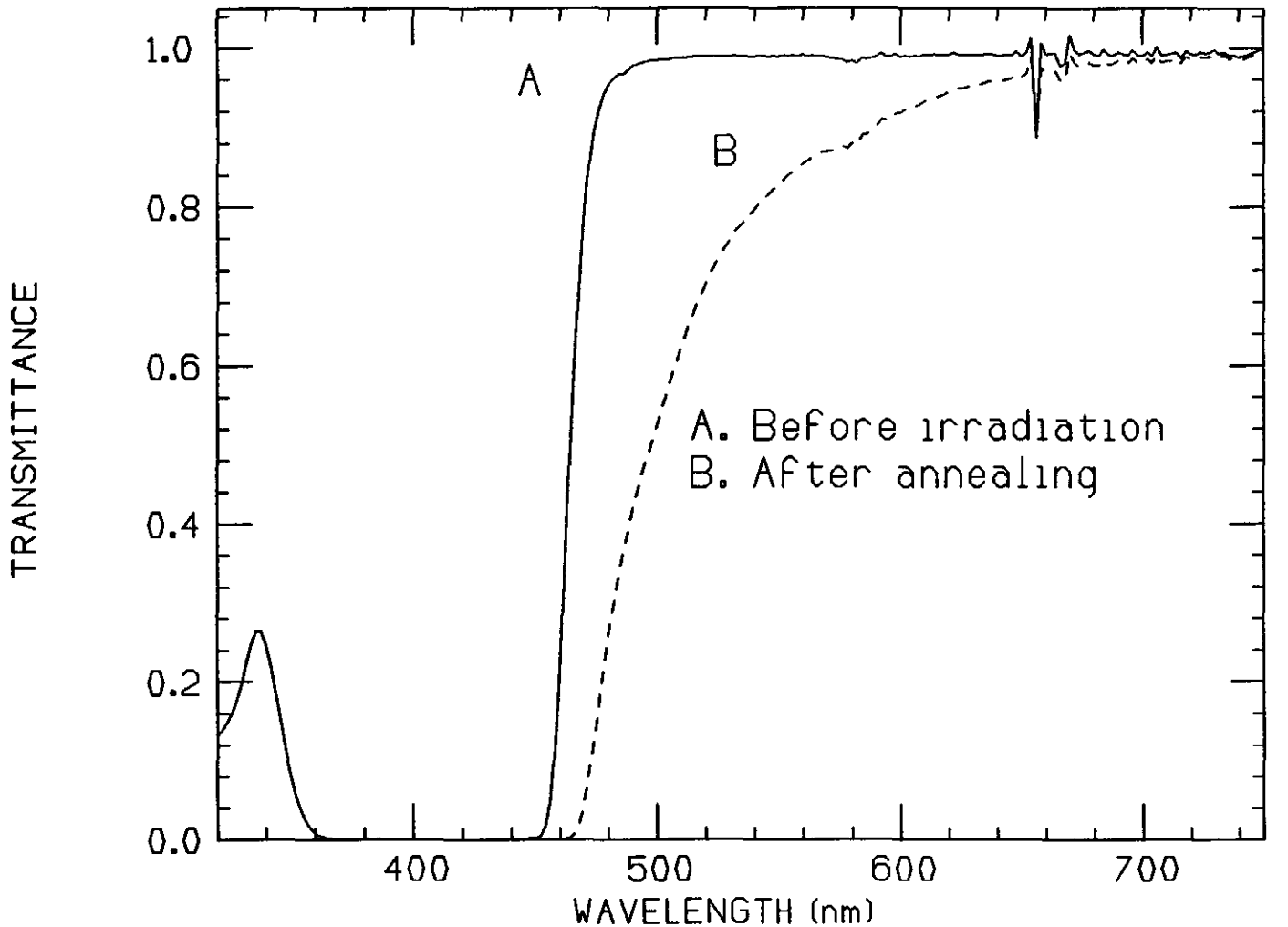


0.02% C314T - HIGH DOSE RATE IRRADIATION IN AIR



0.02% C338 - HIGH DOSE RATE IRRADIATION IN AIR



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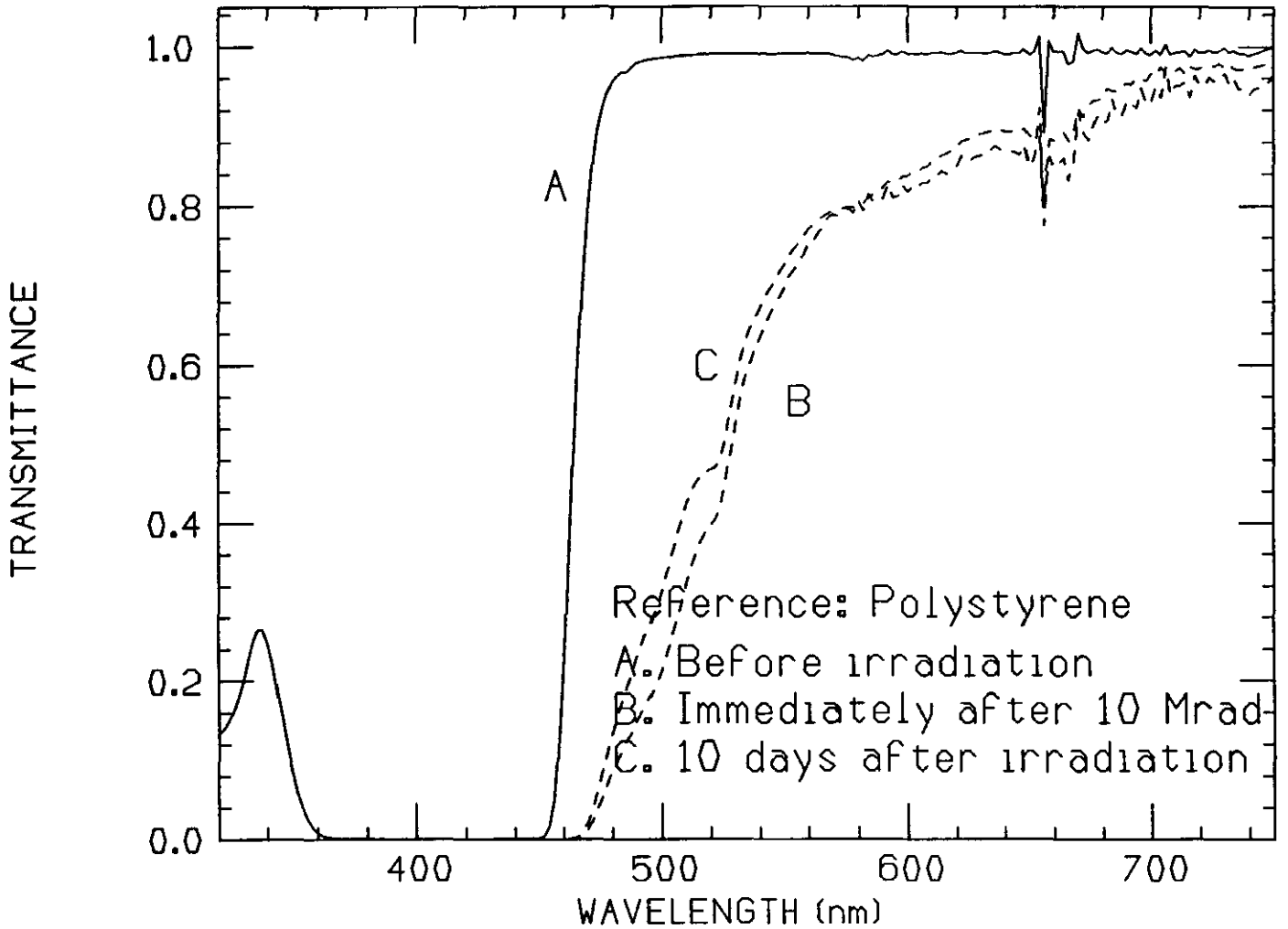

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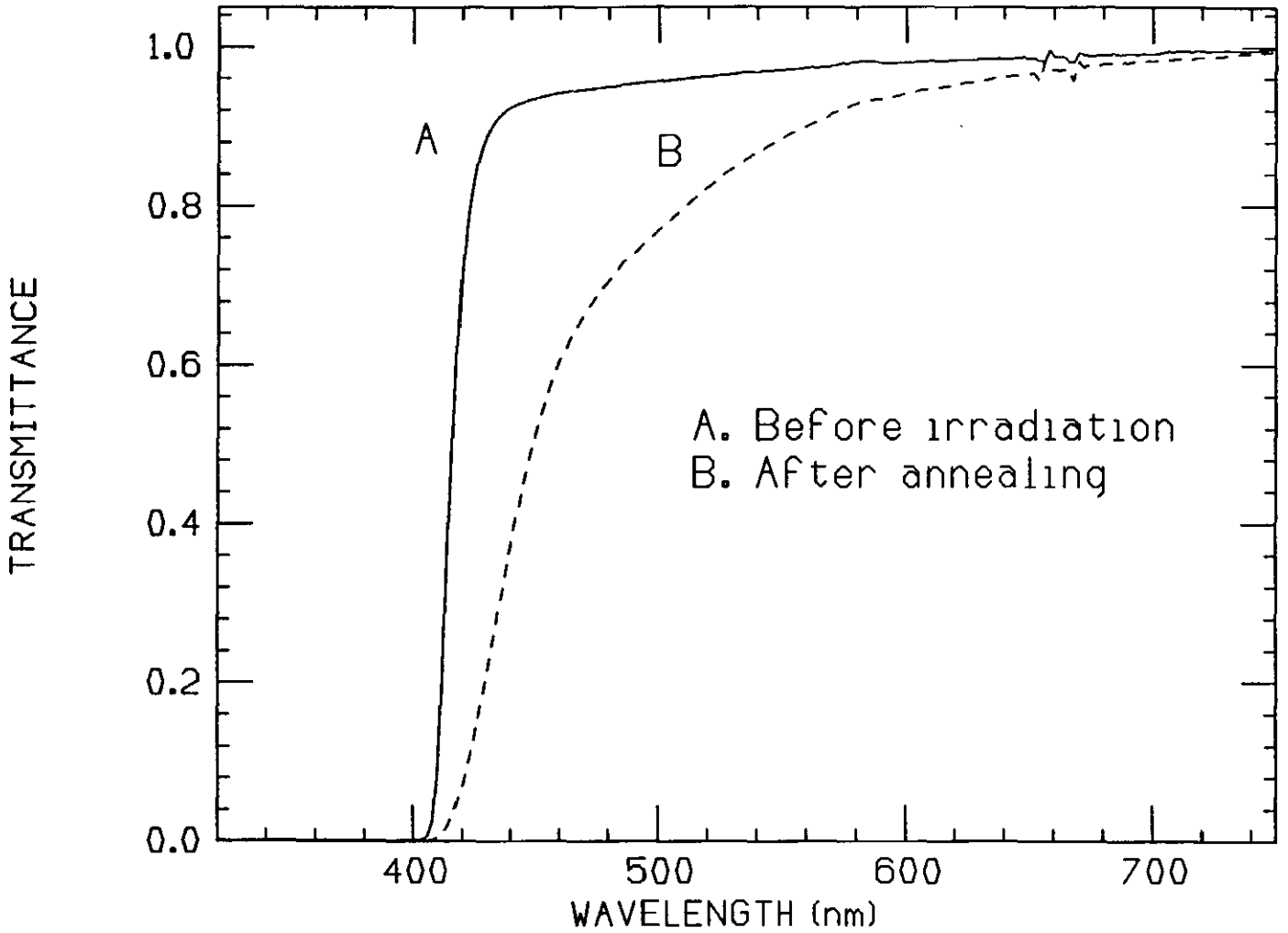

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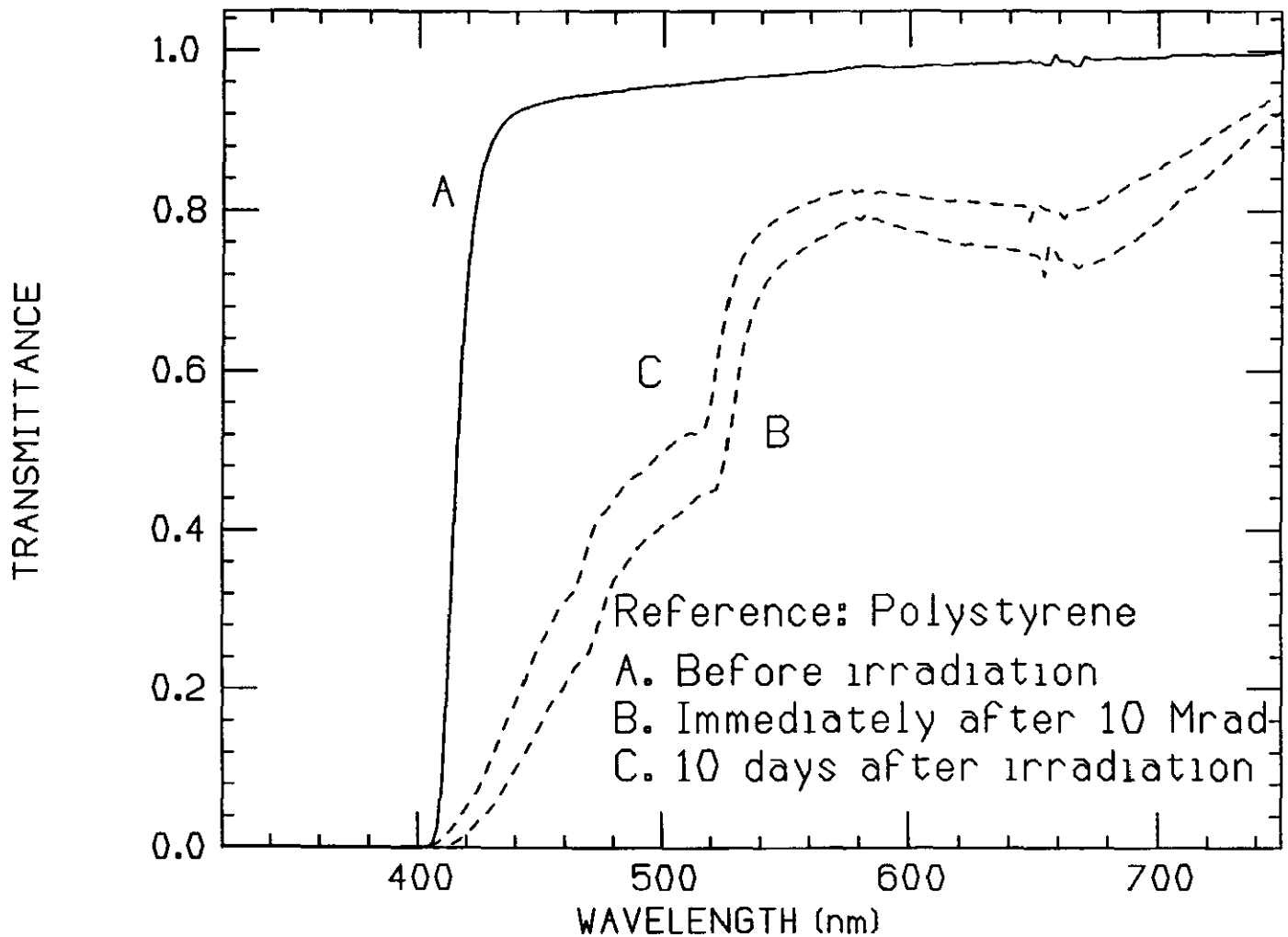

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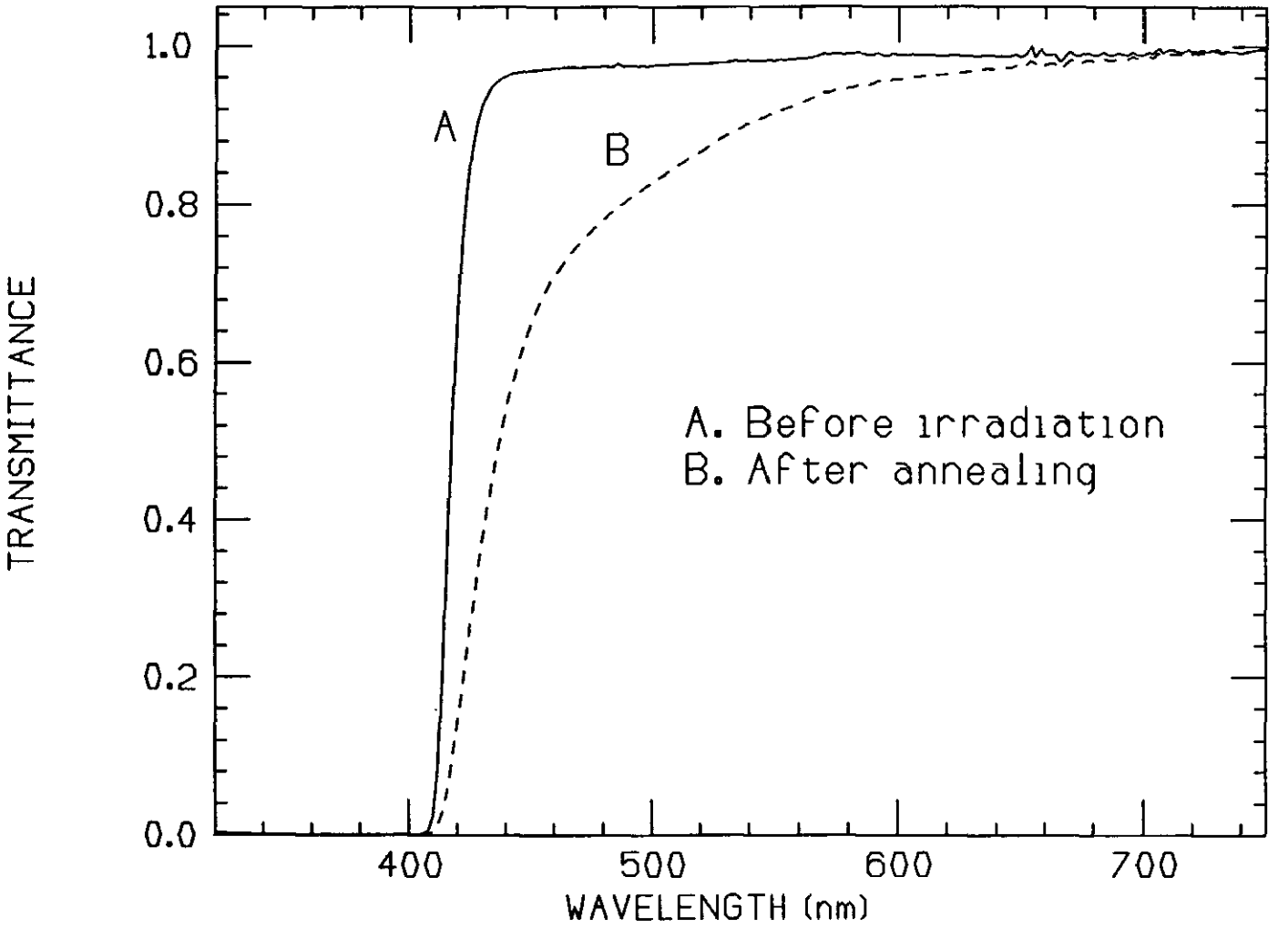

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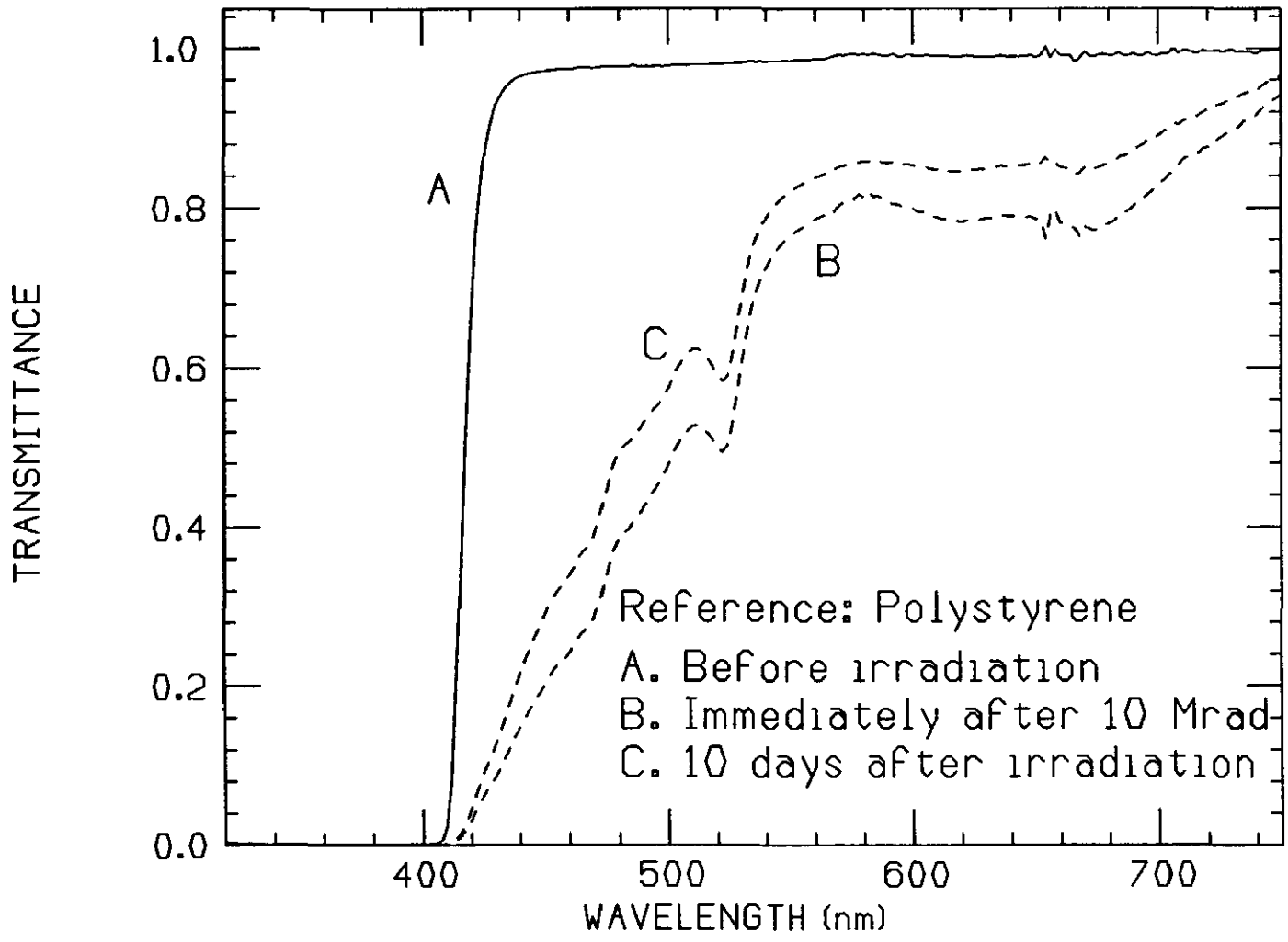

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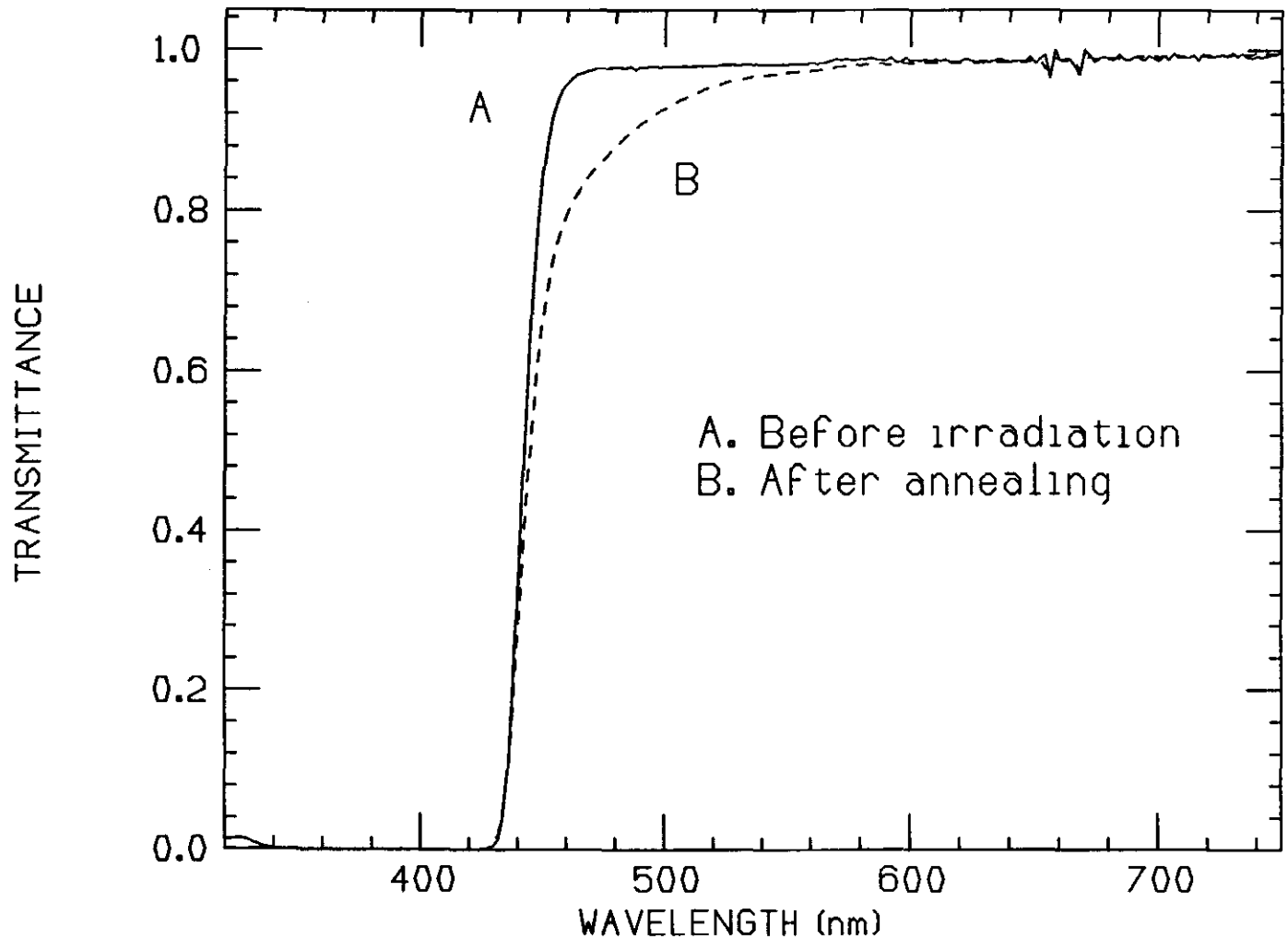
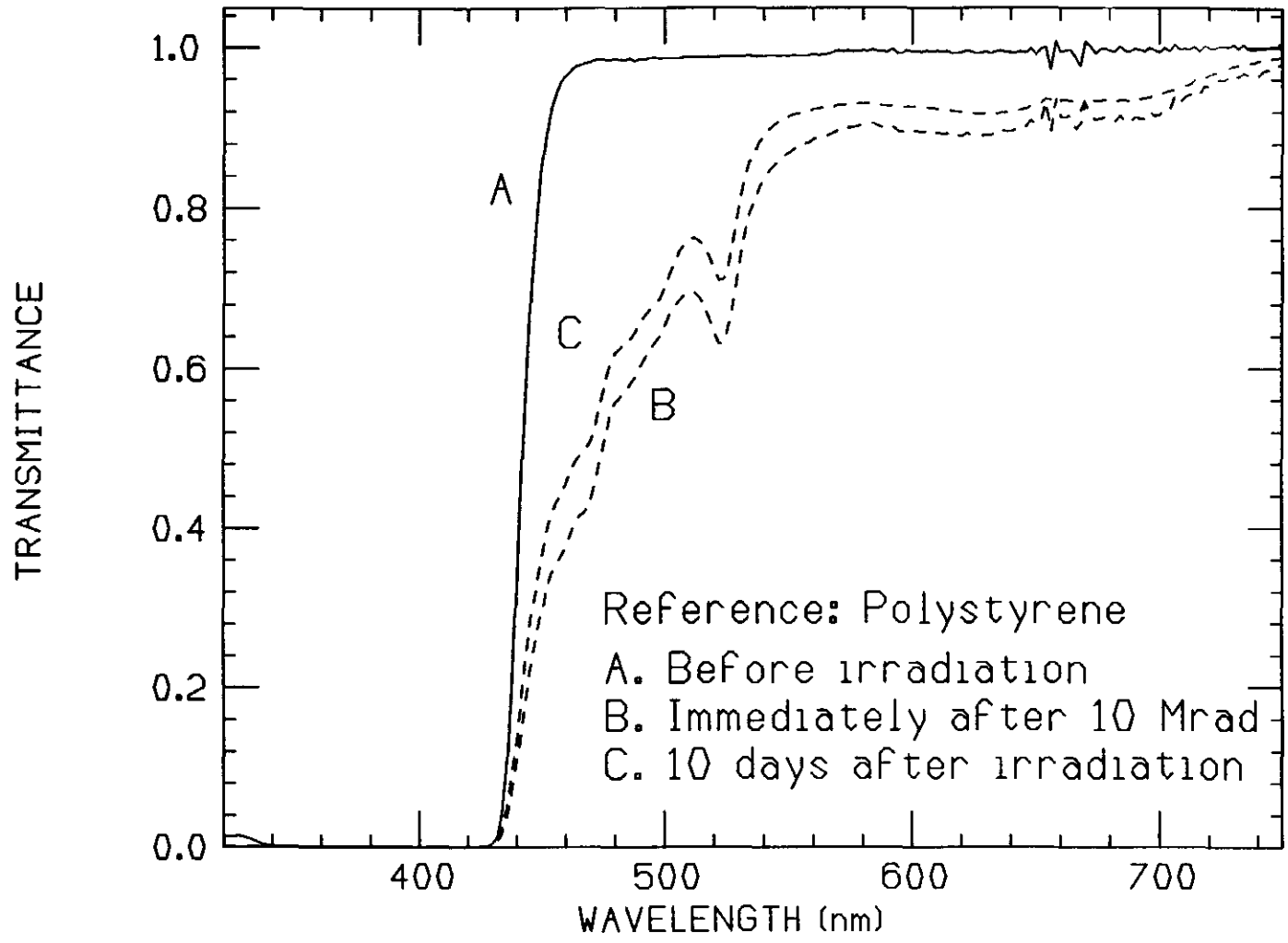


0.02% C485 - HIGH DOSE RATE IRRADIATION IN AIR



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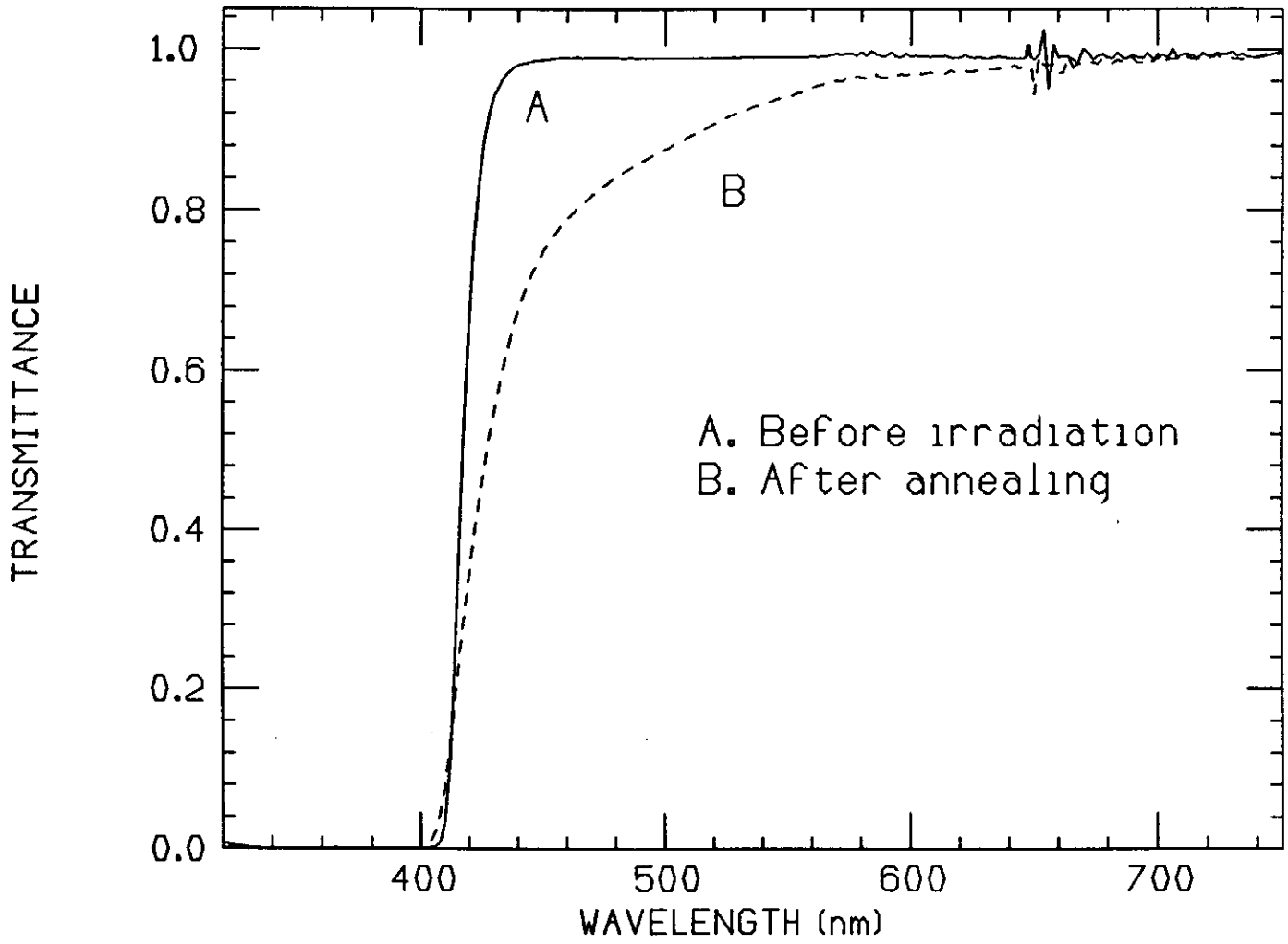

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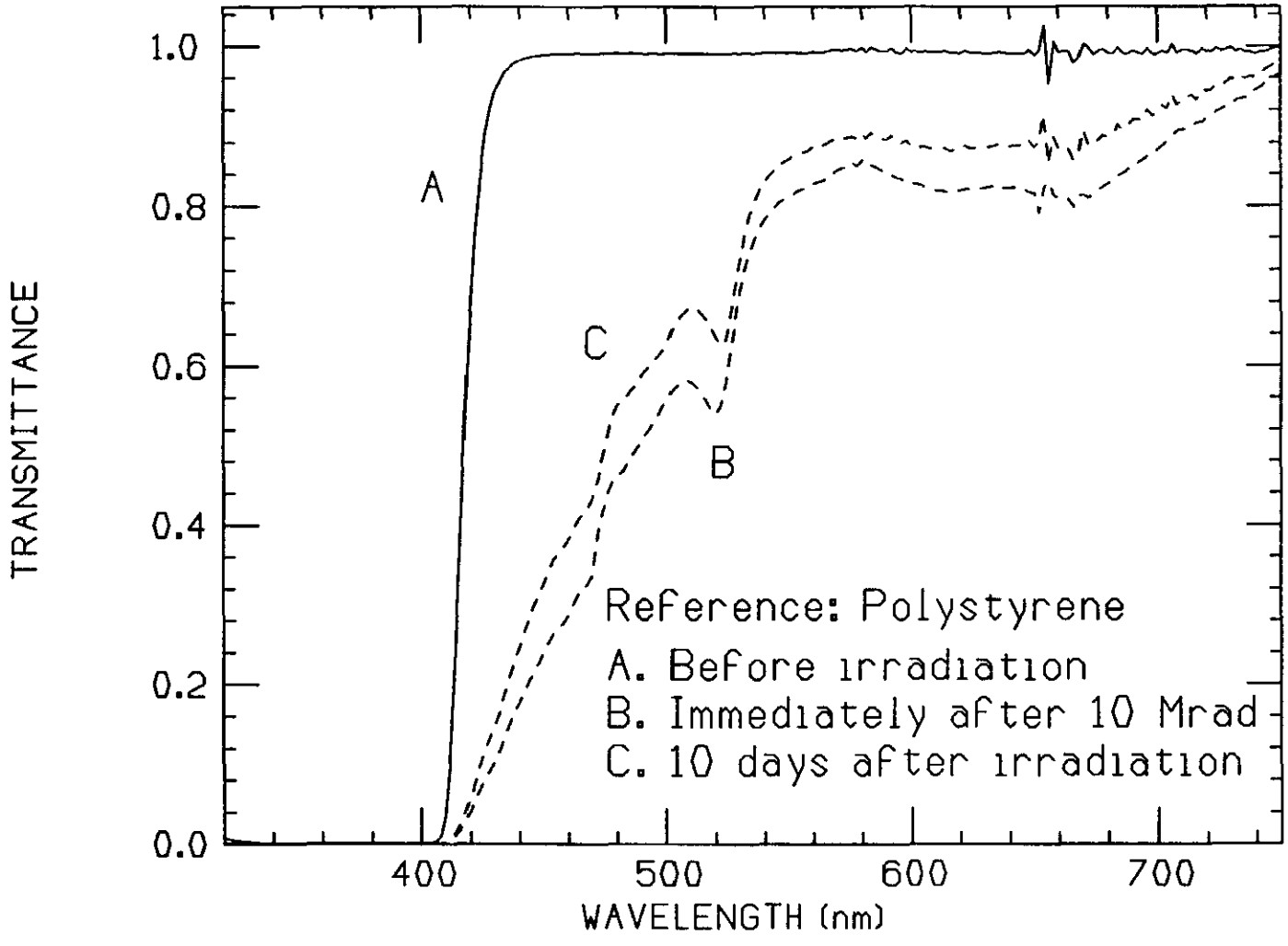

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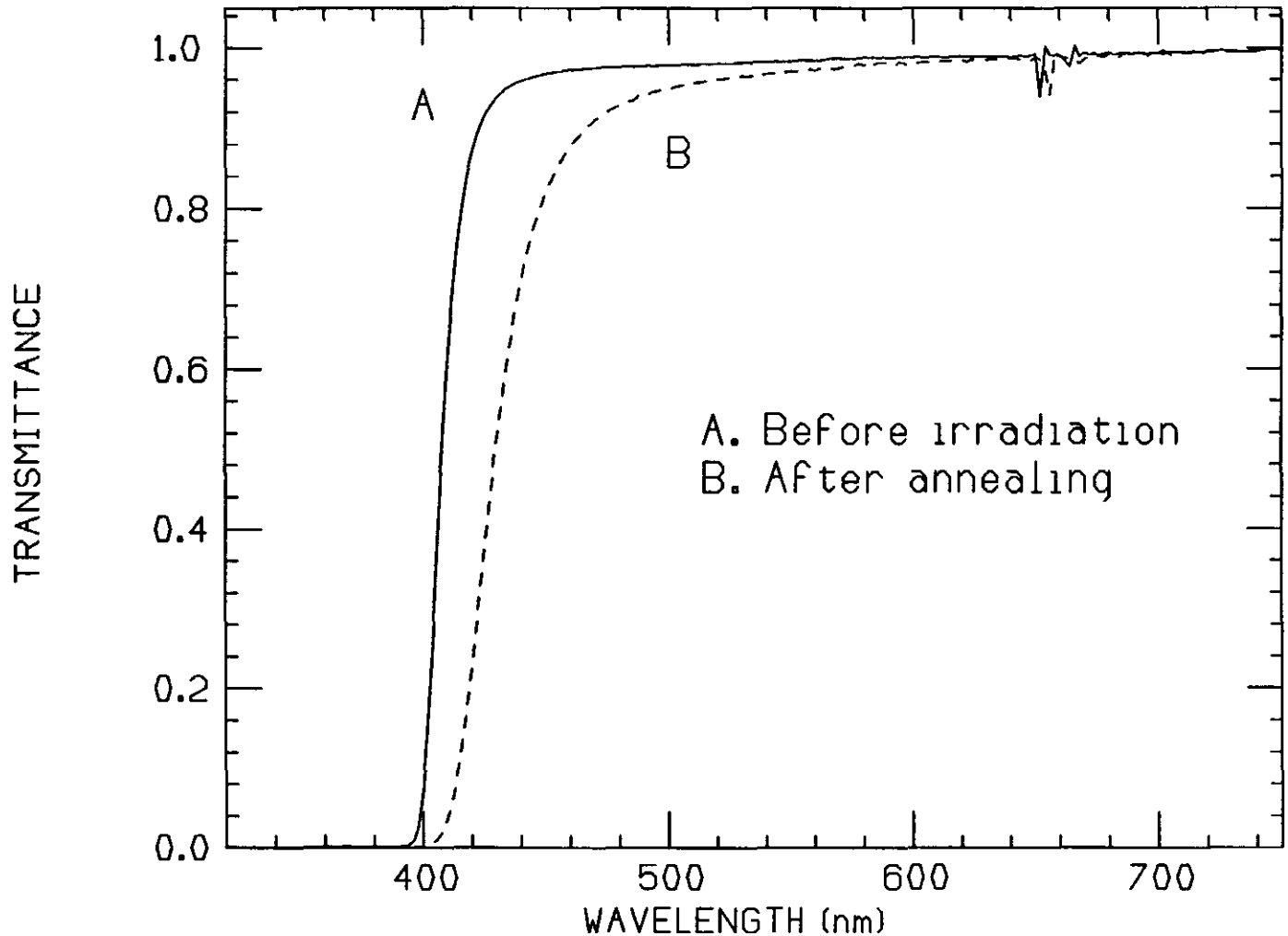
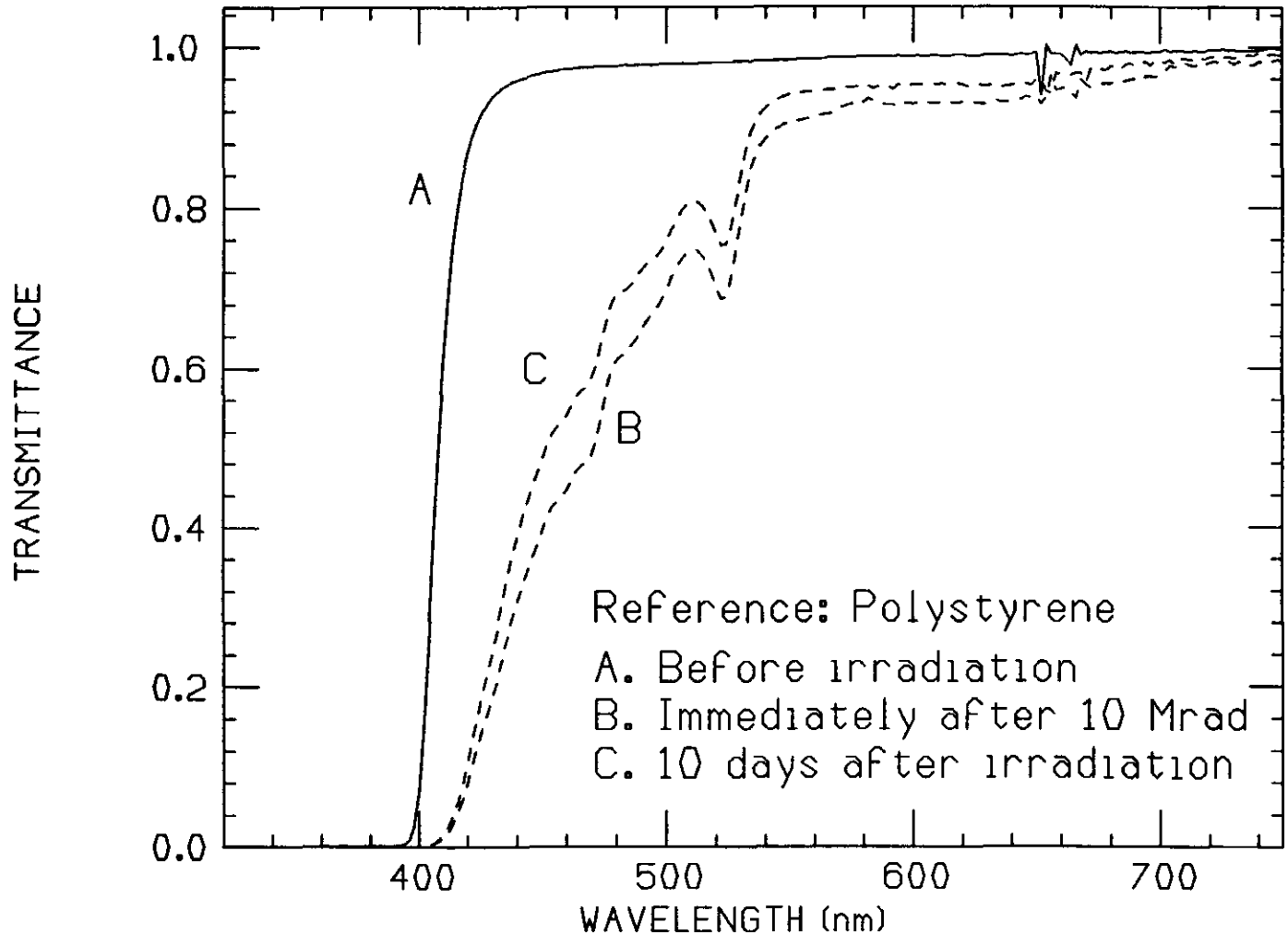


0.02% C490 - HIGH DOSE RATE IRRADIATION IN AIR



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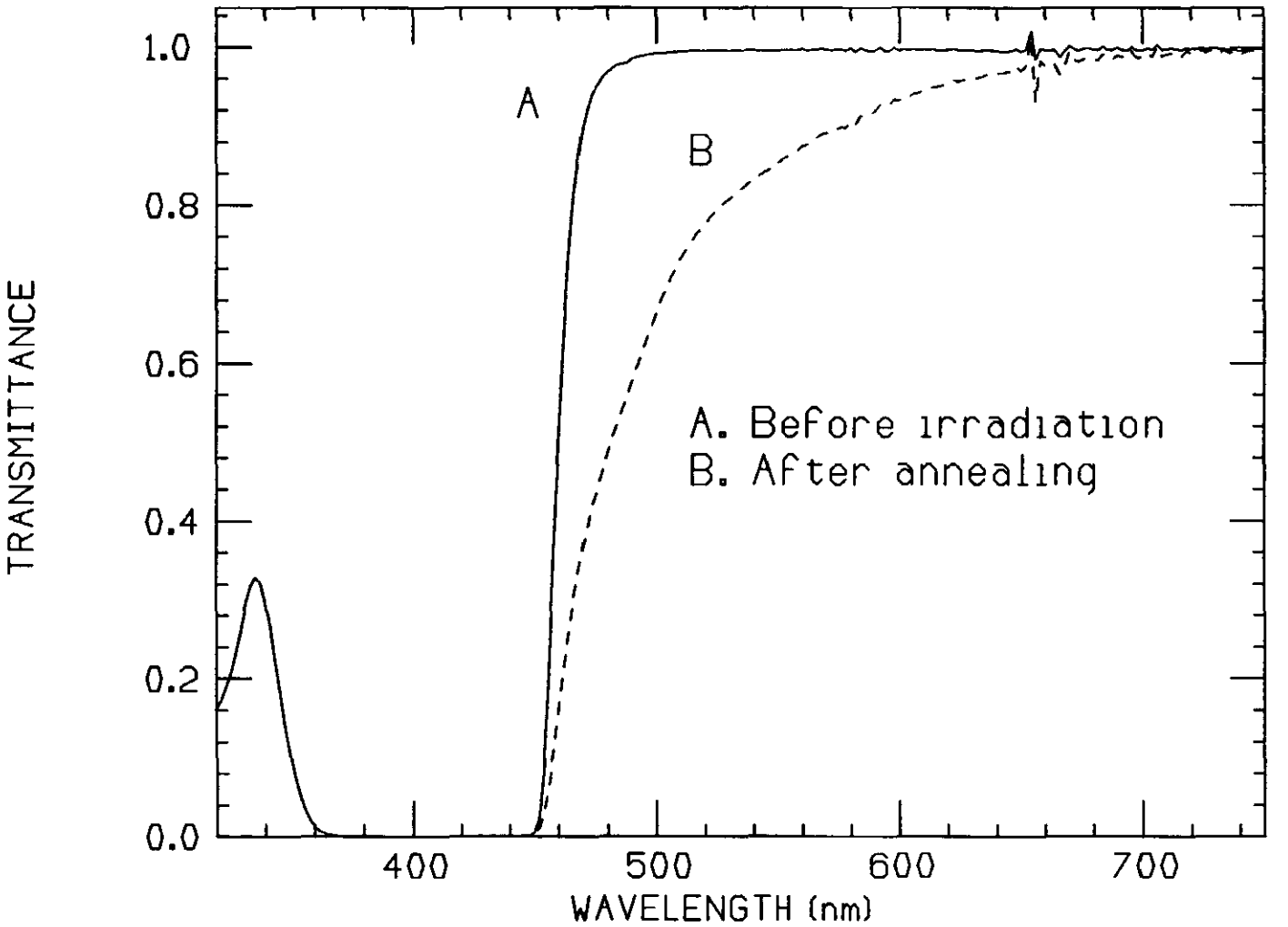

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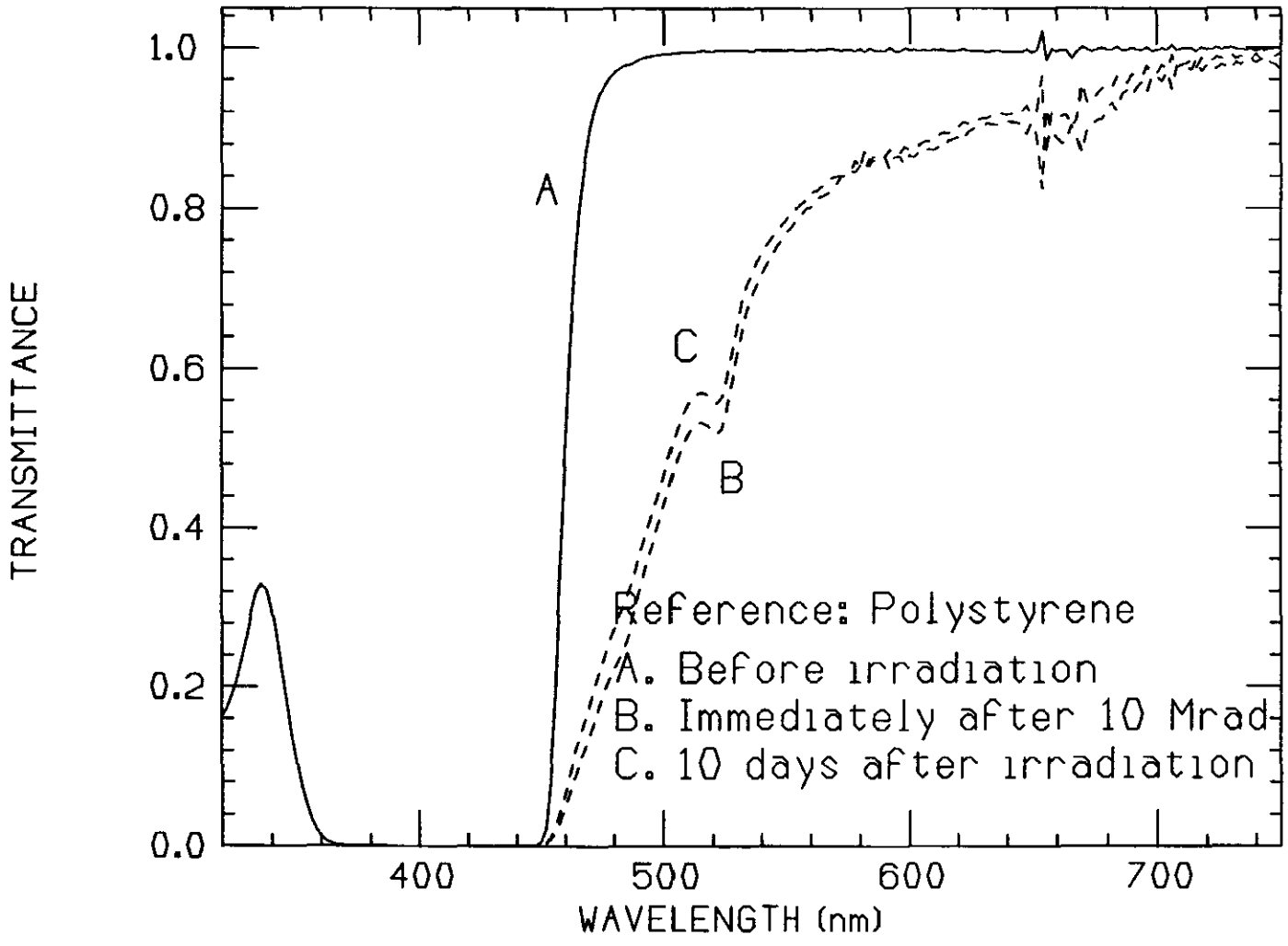

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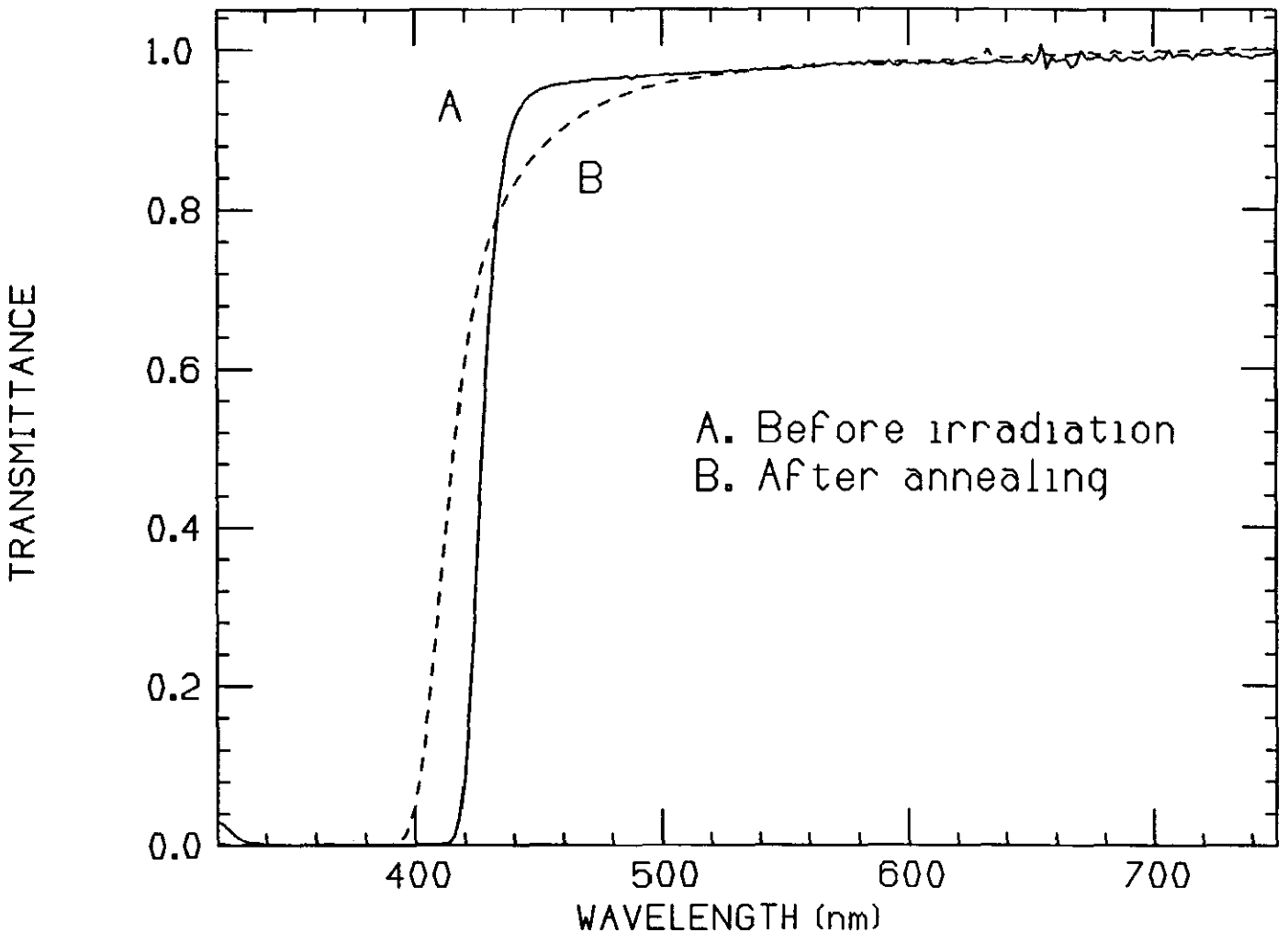
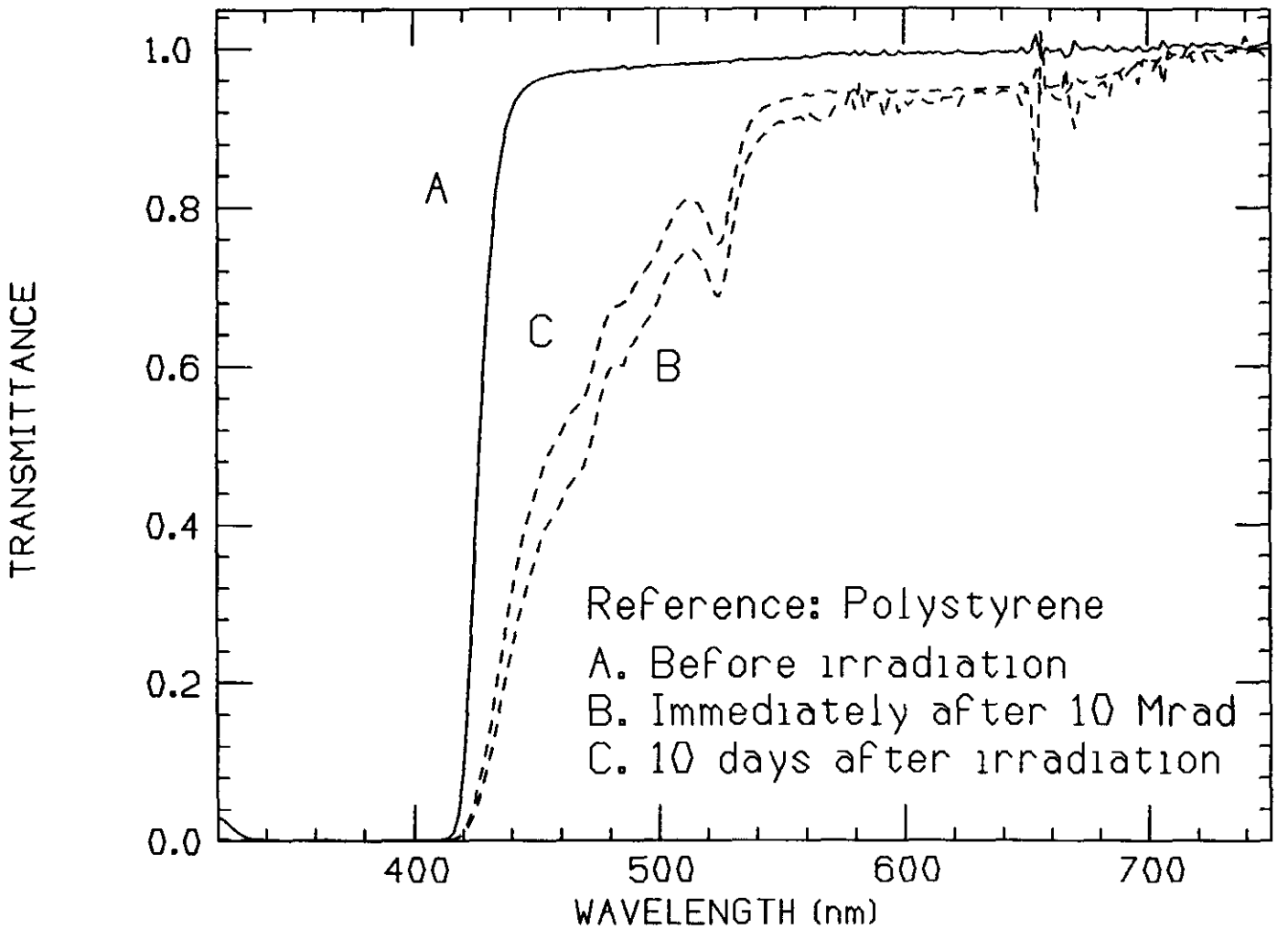


0.02% C500 - HIGH DOSE RATE IRRADIATION IN AIR



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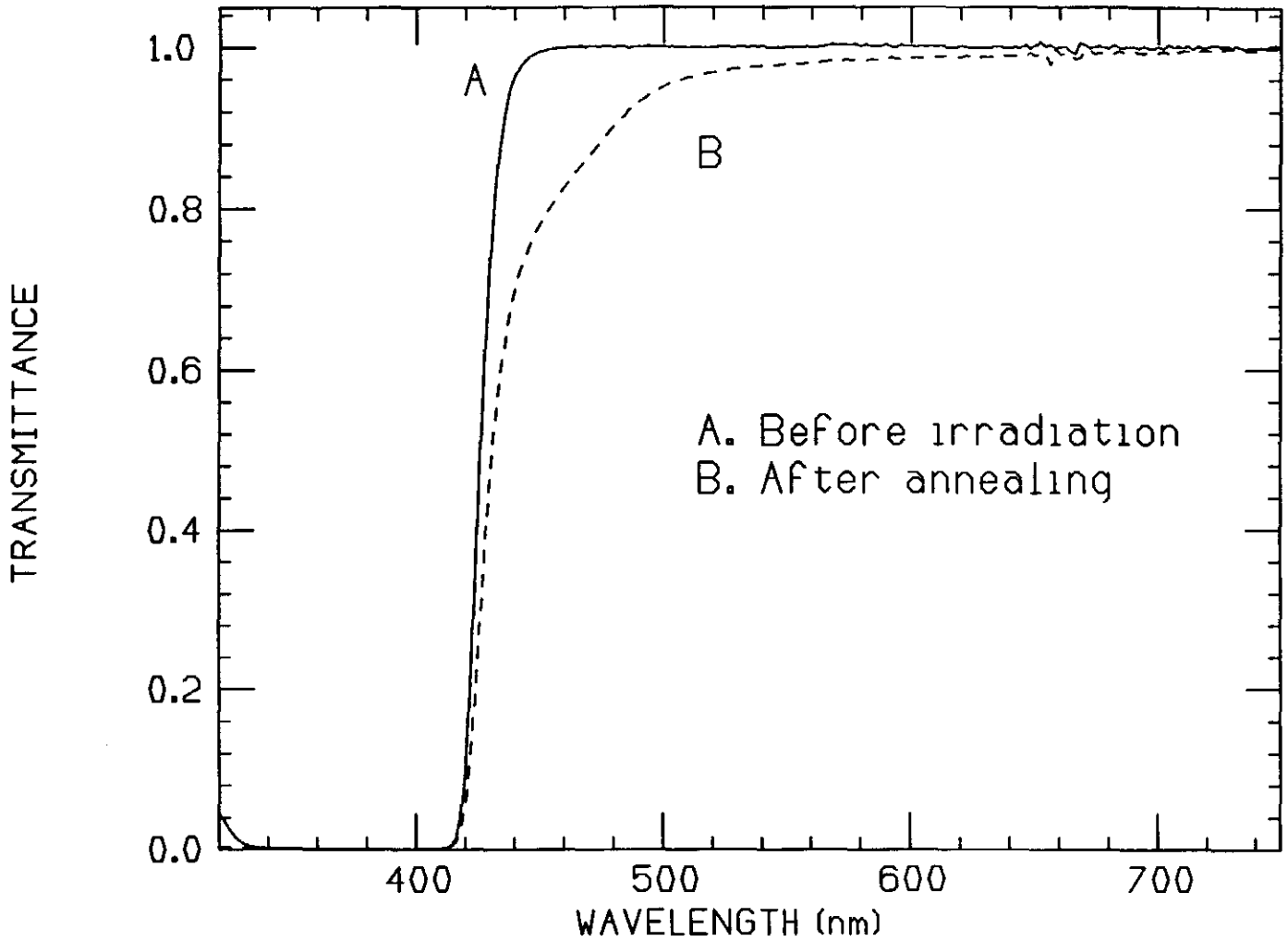

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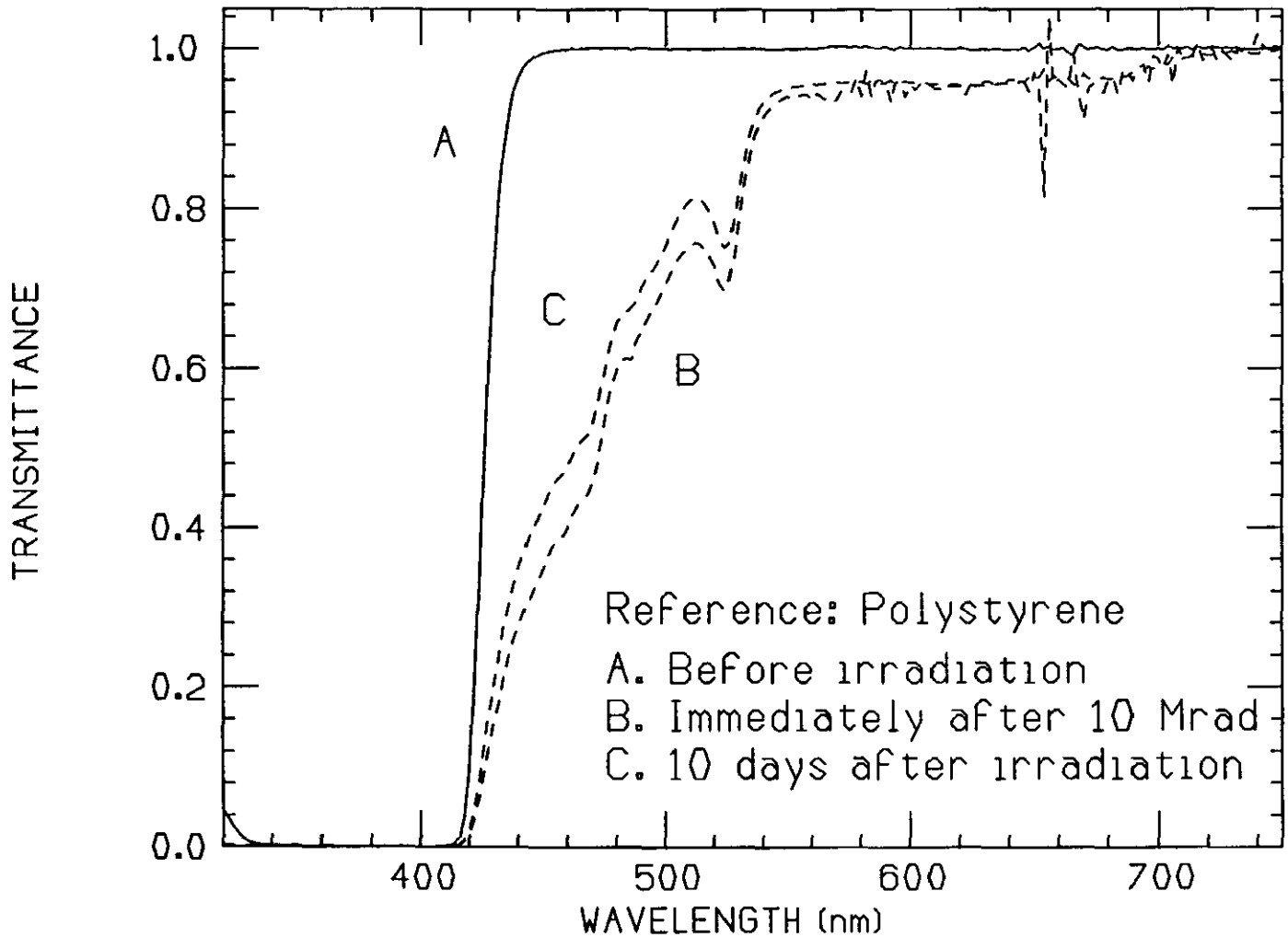

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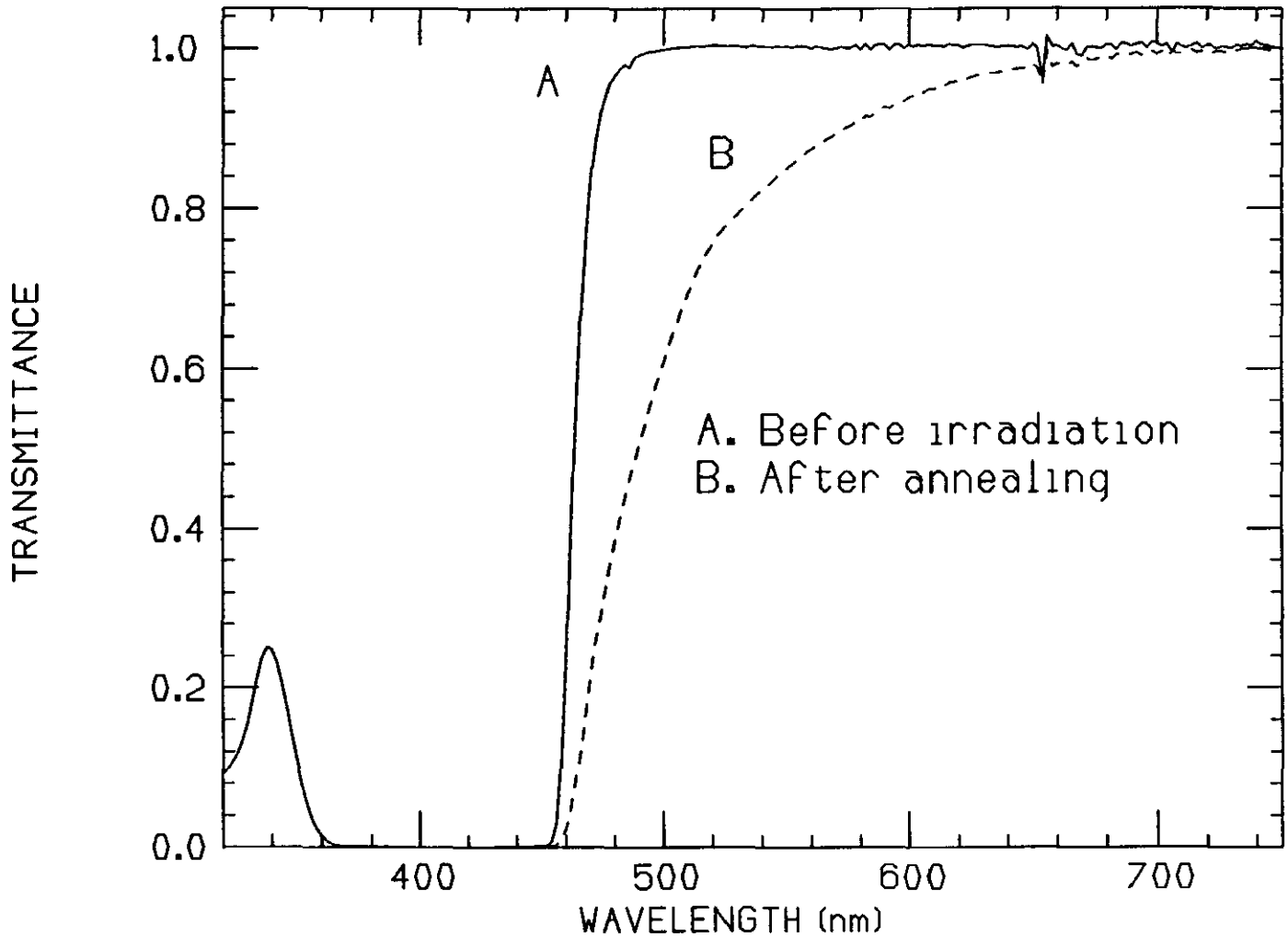

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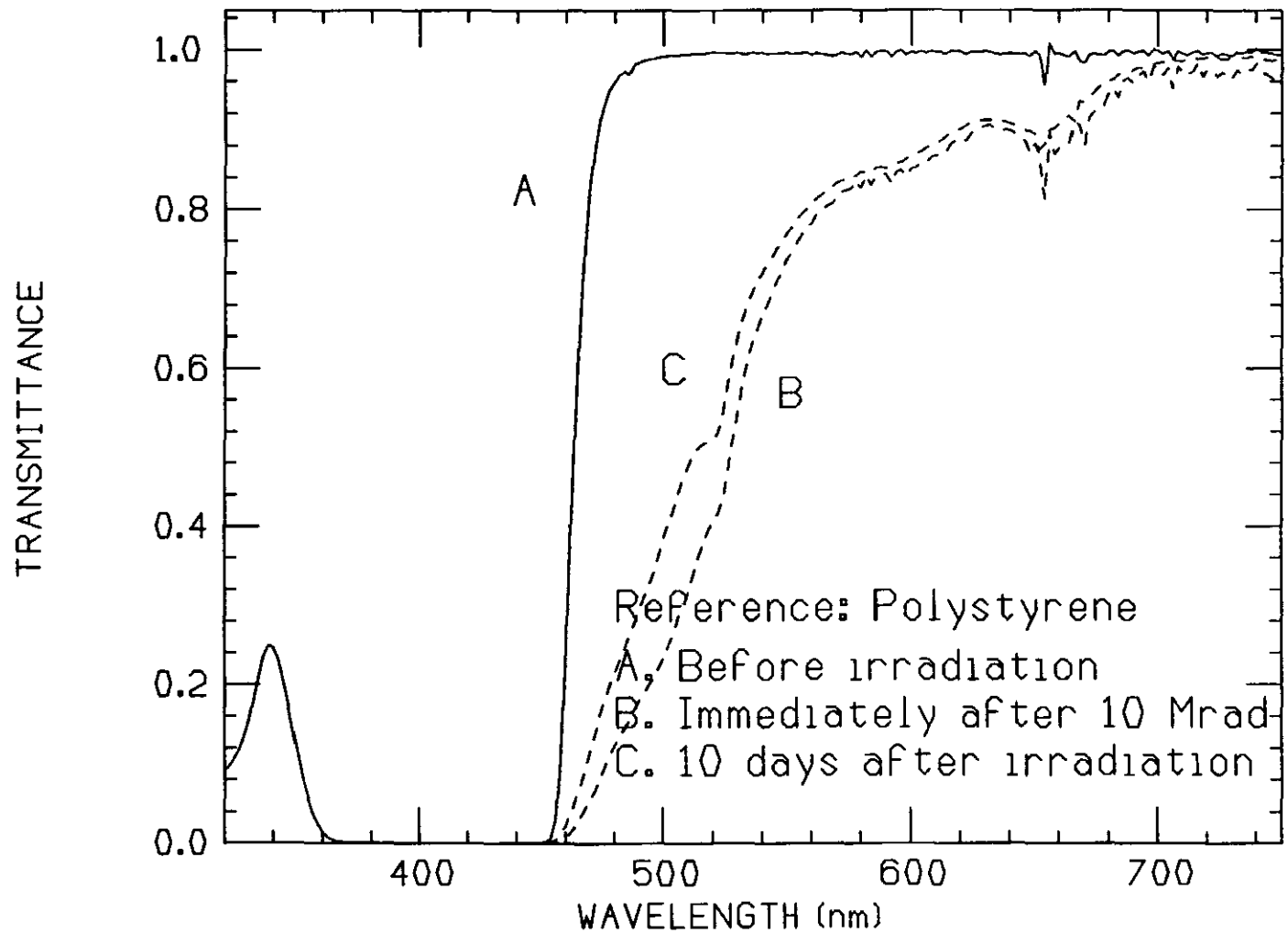

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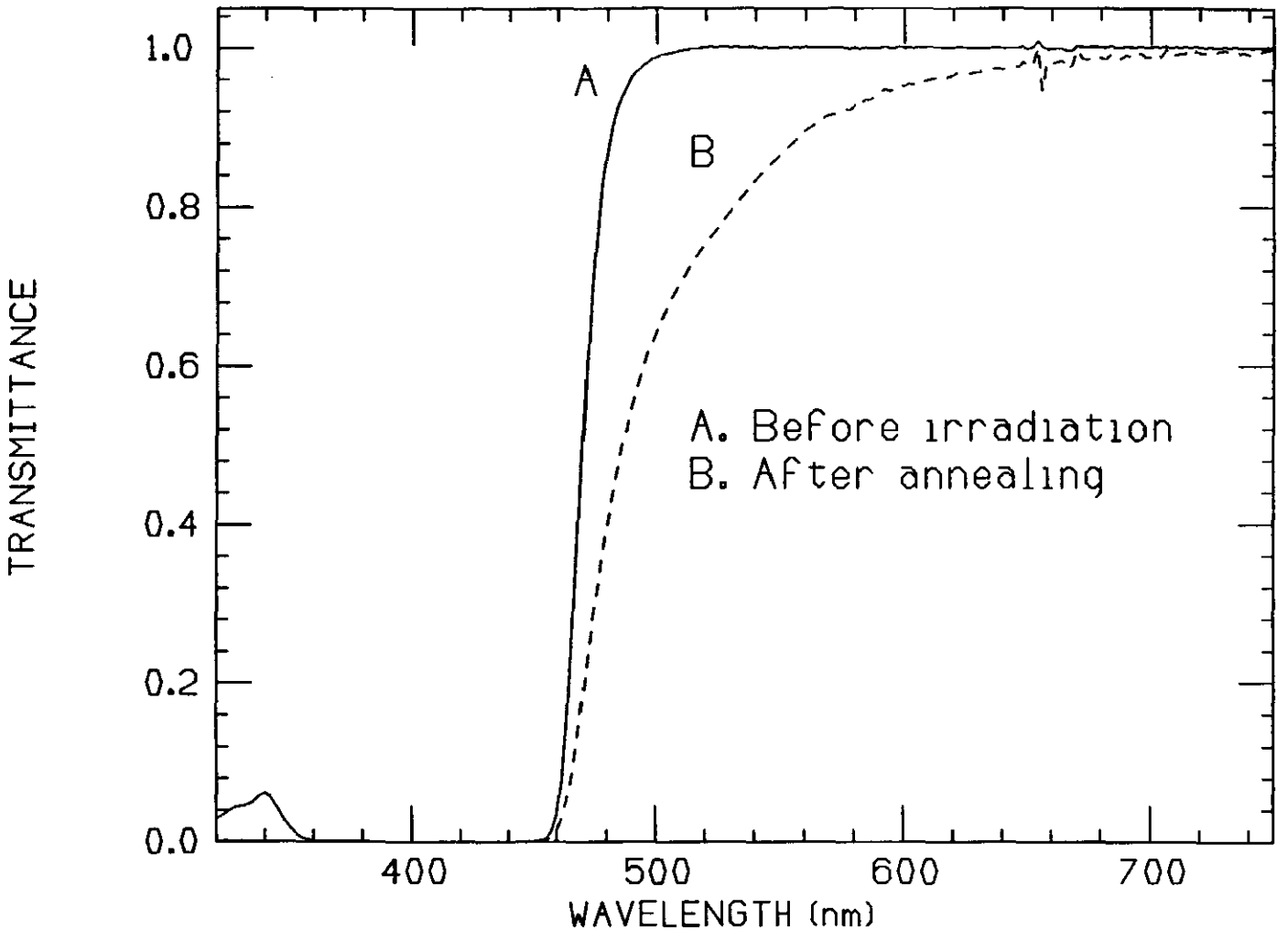

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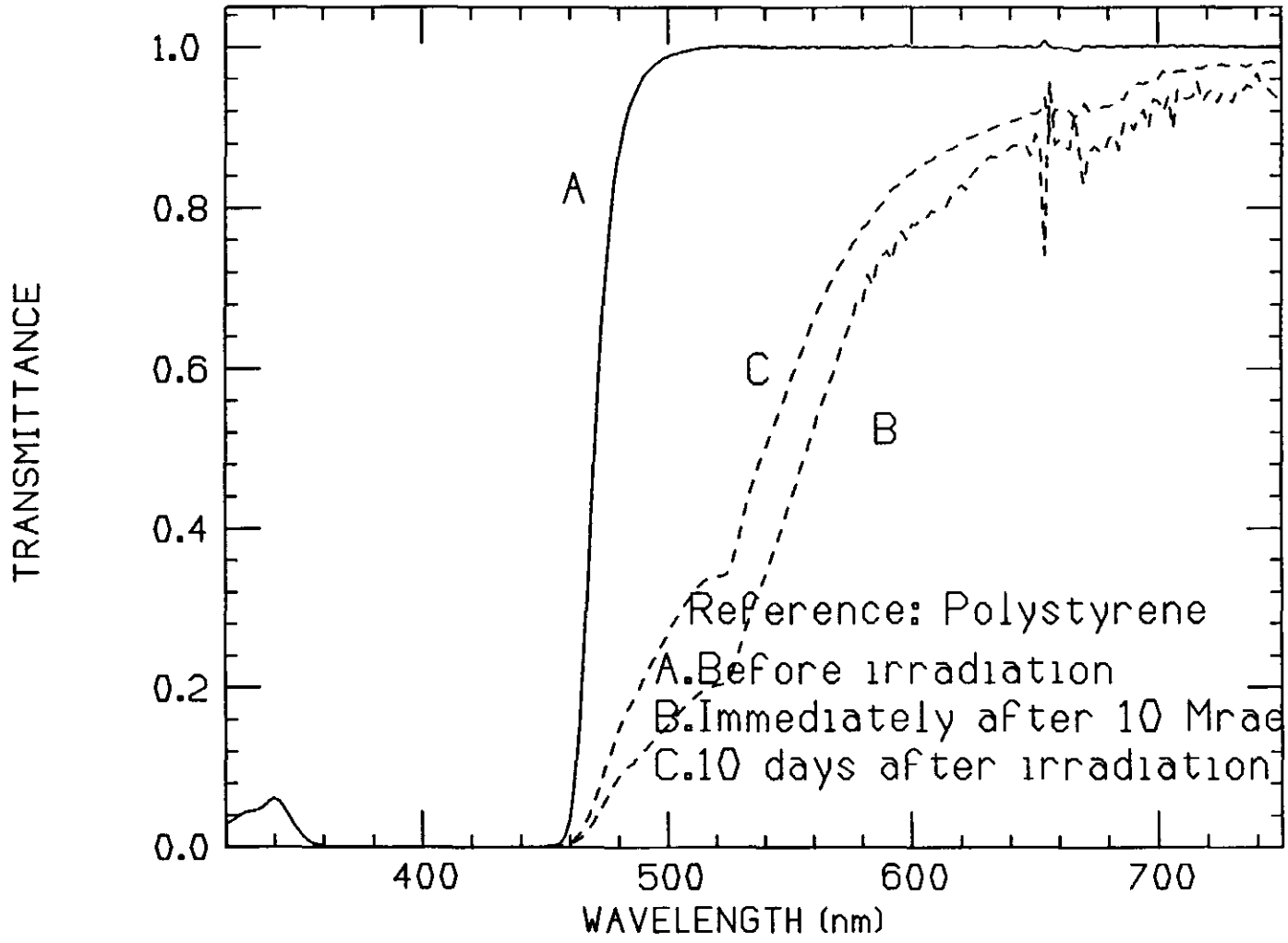

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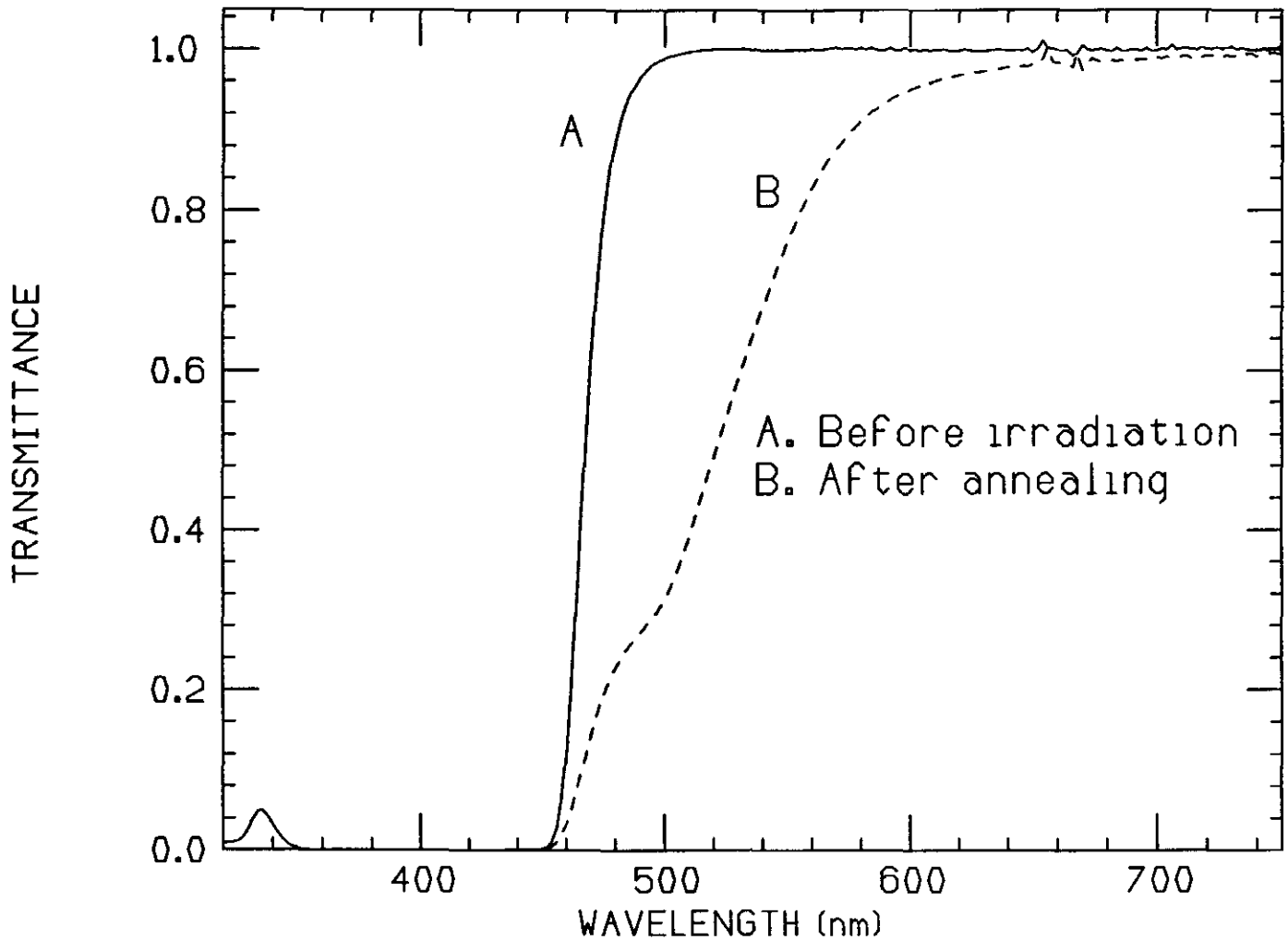

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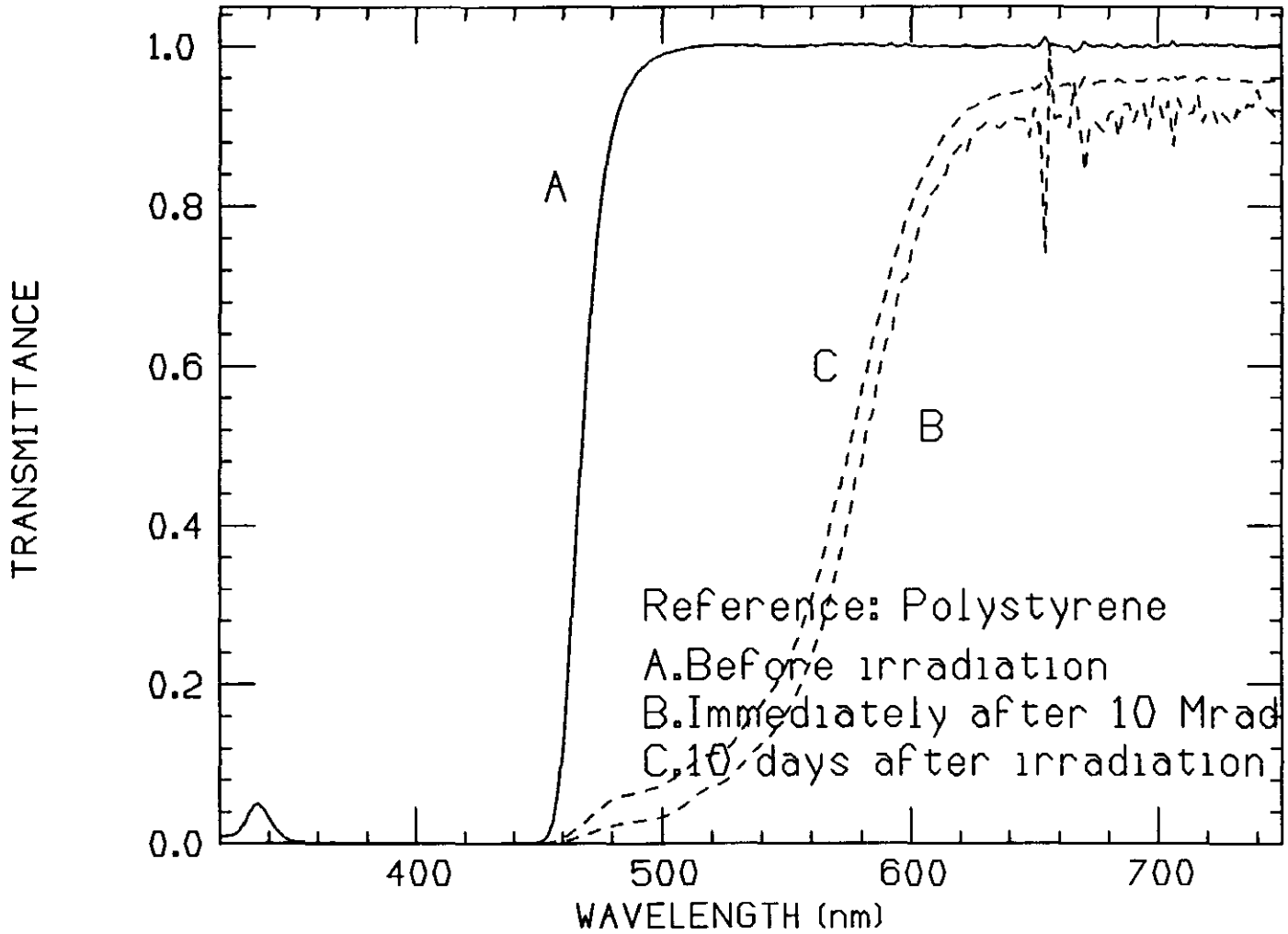

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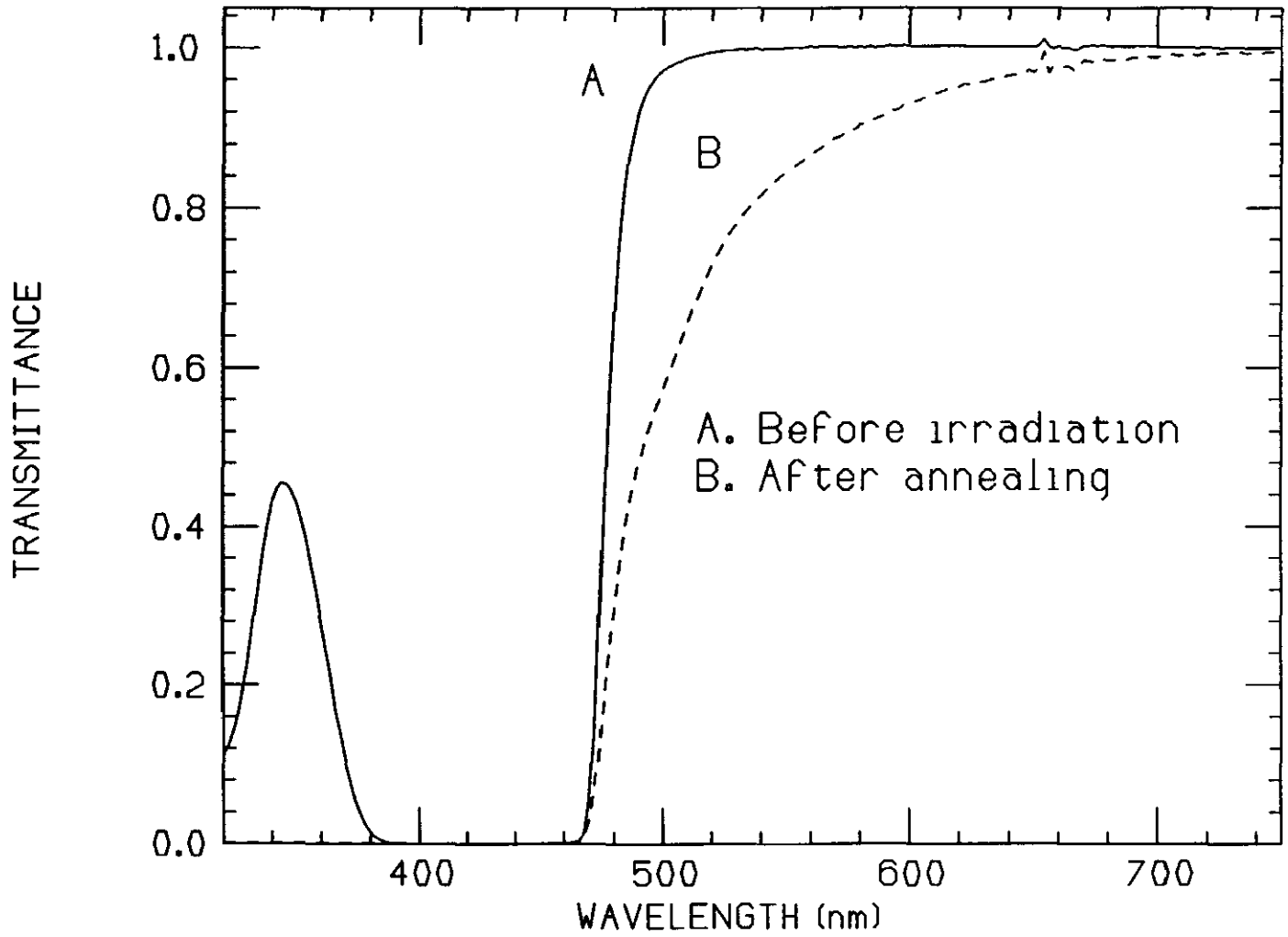

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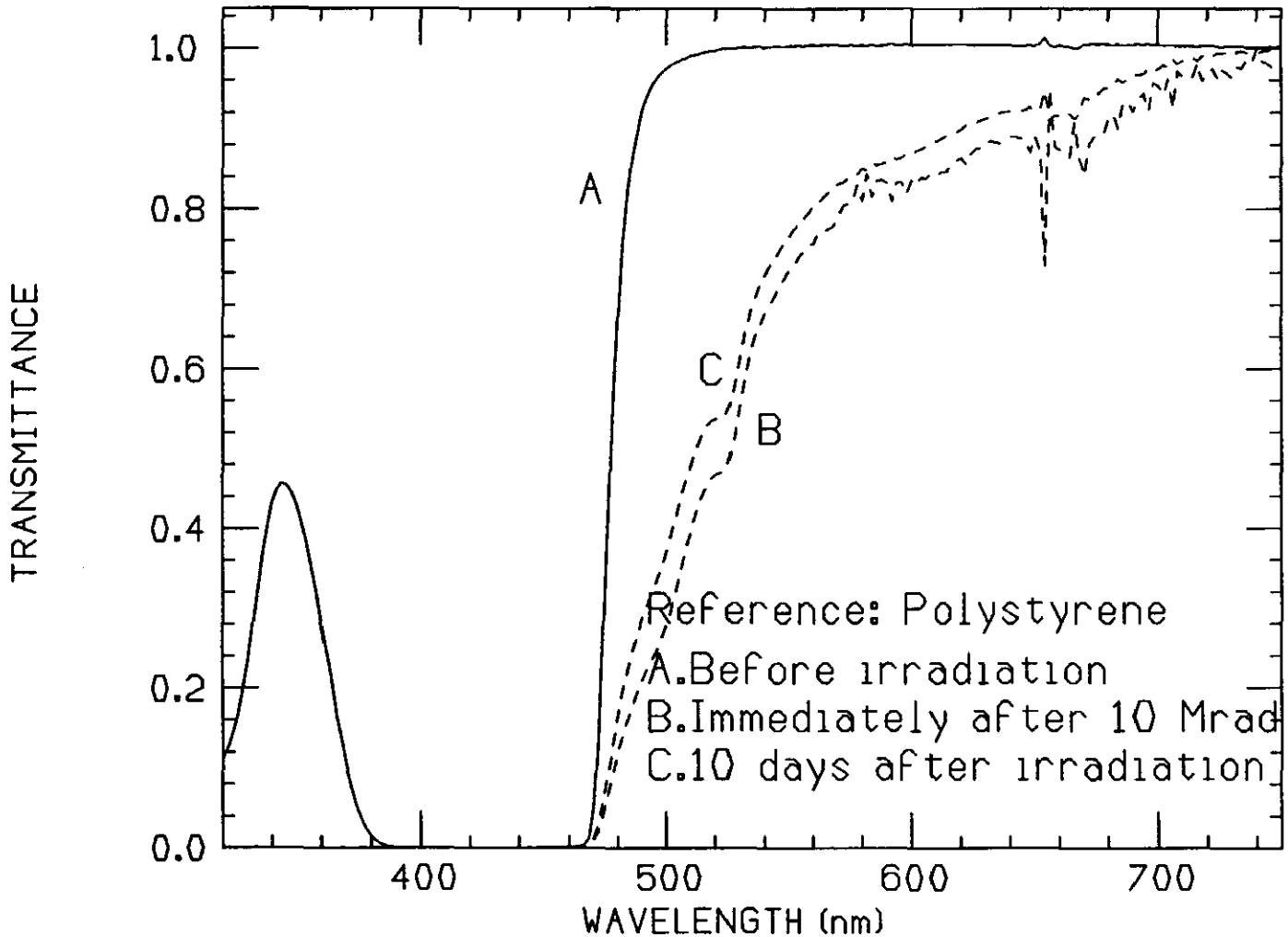

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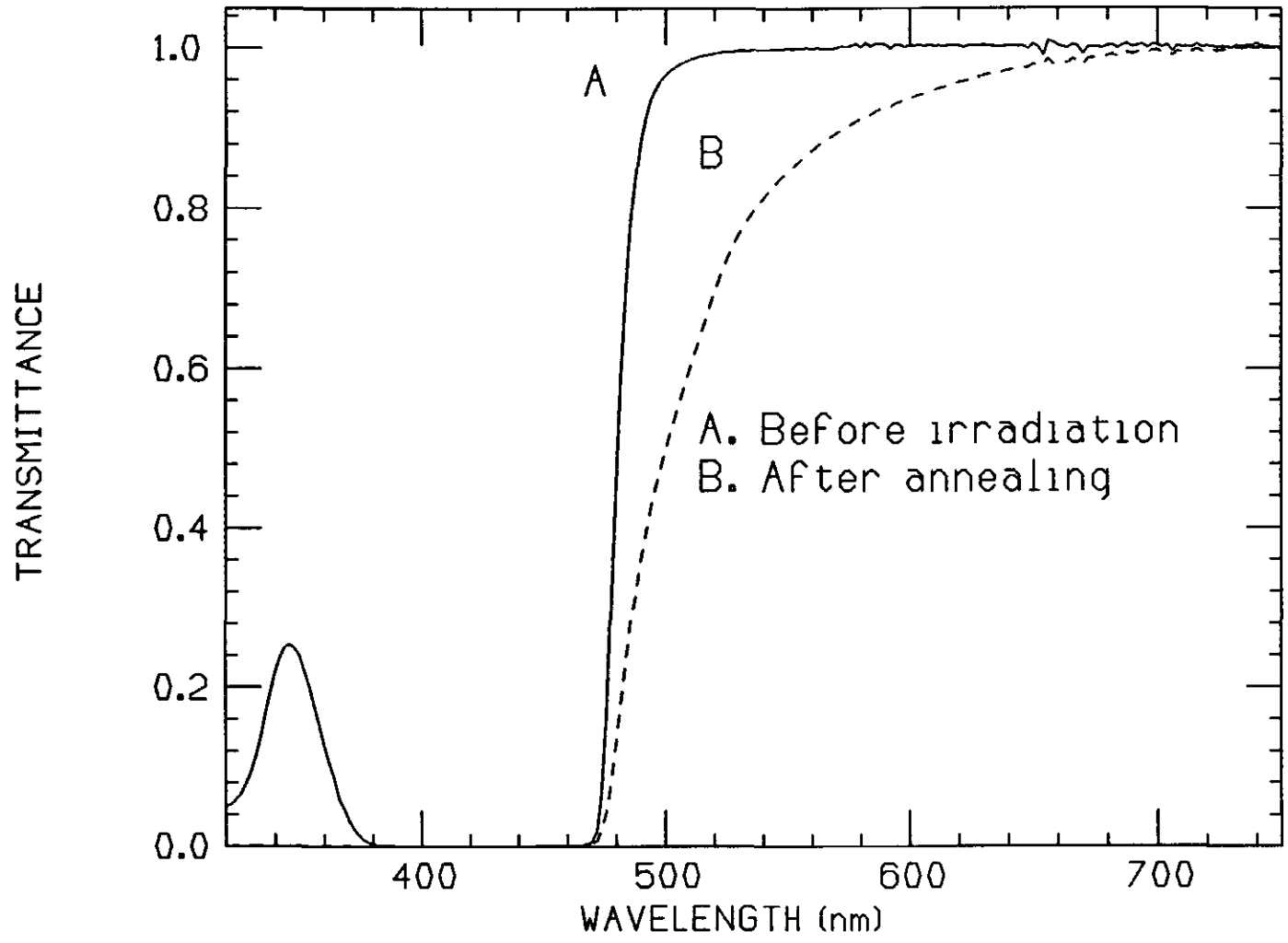

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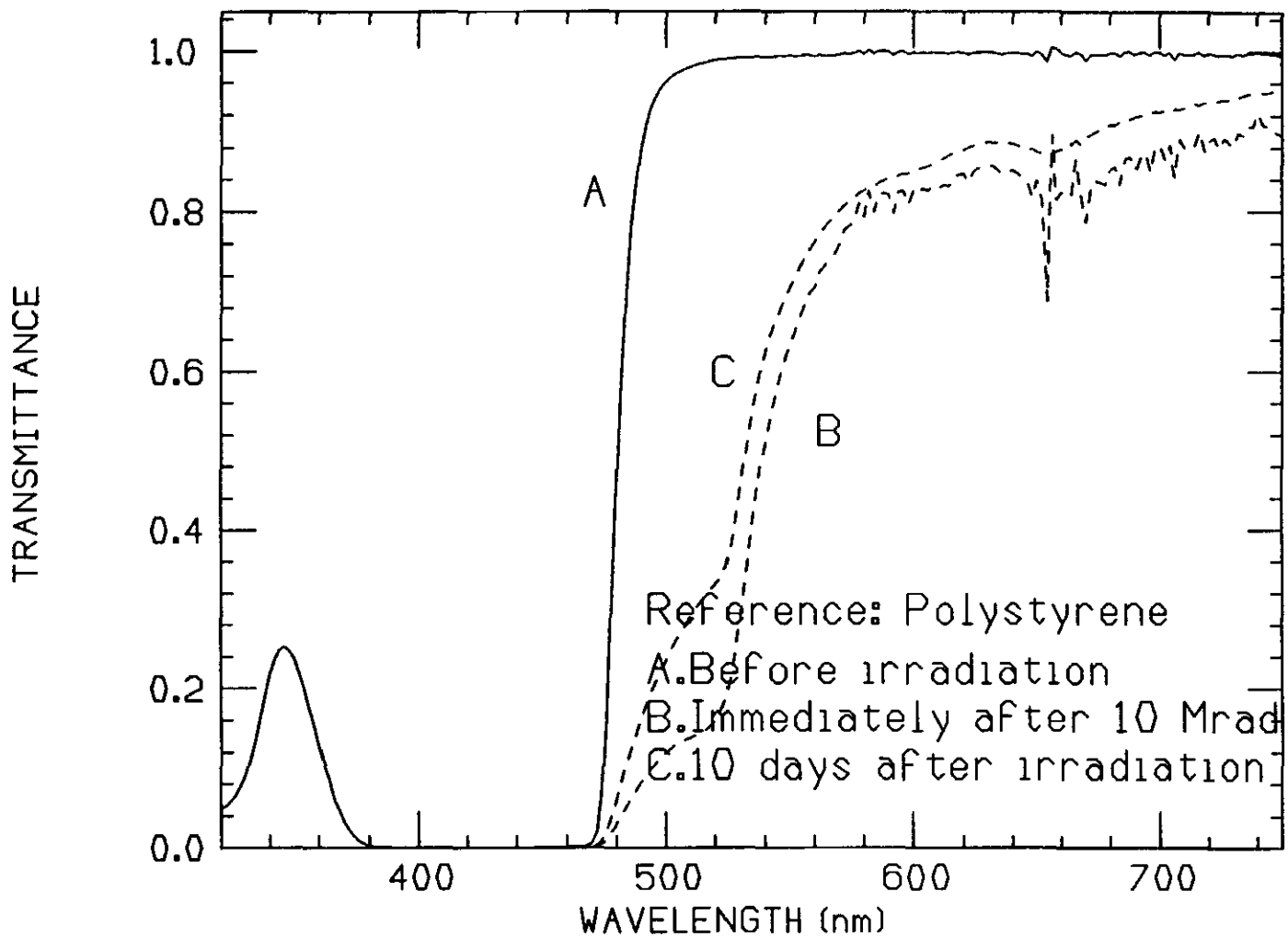

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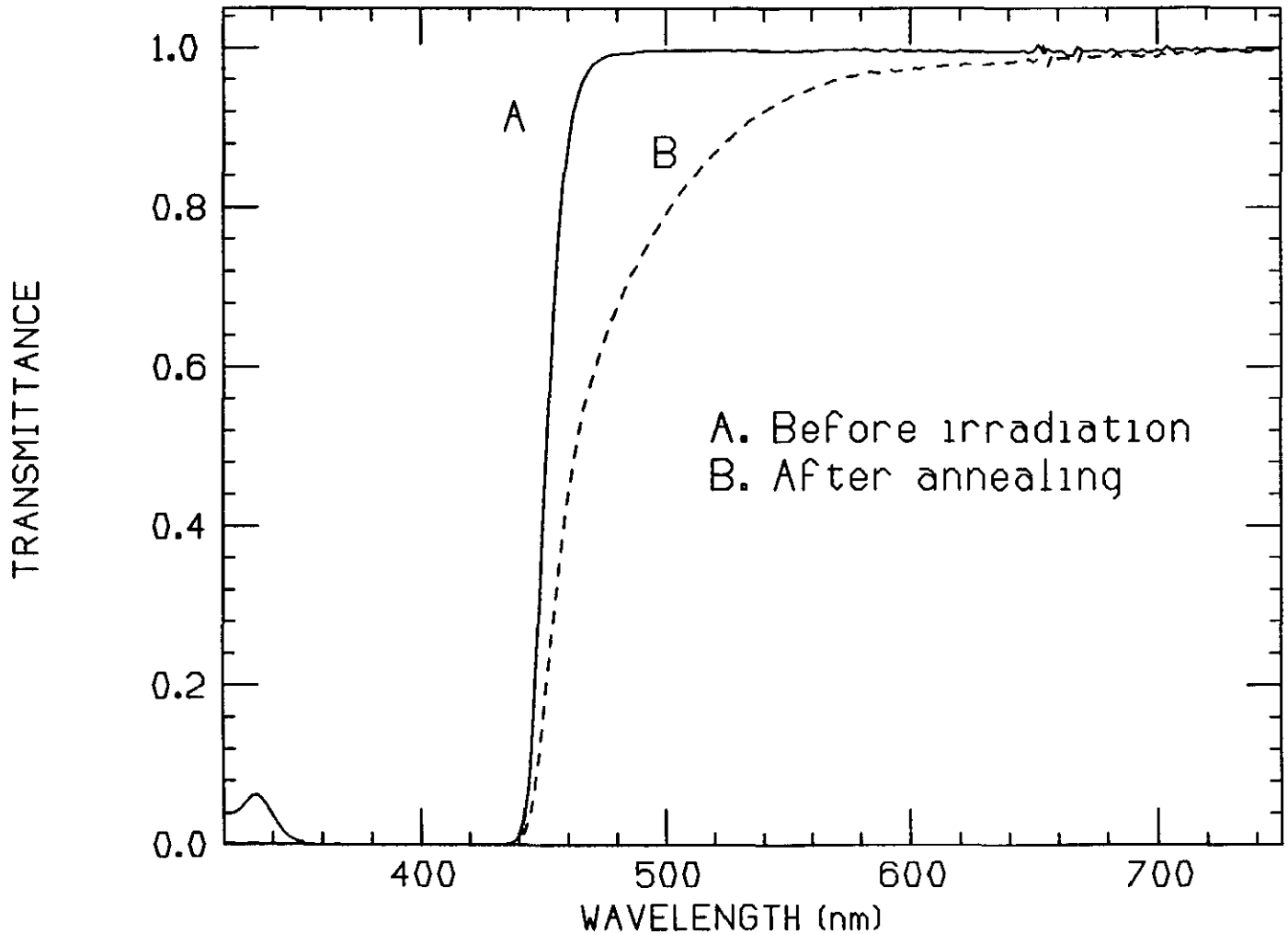

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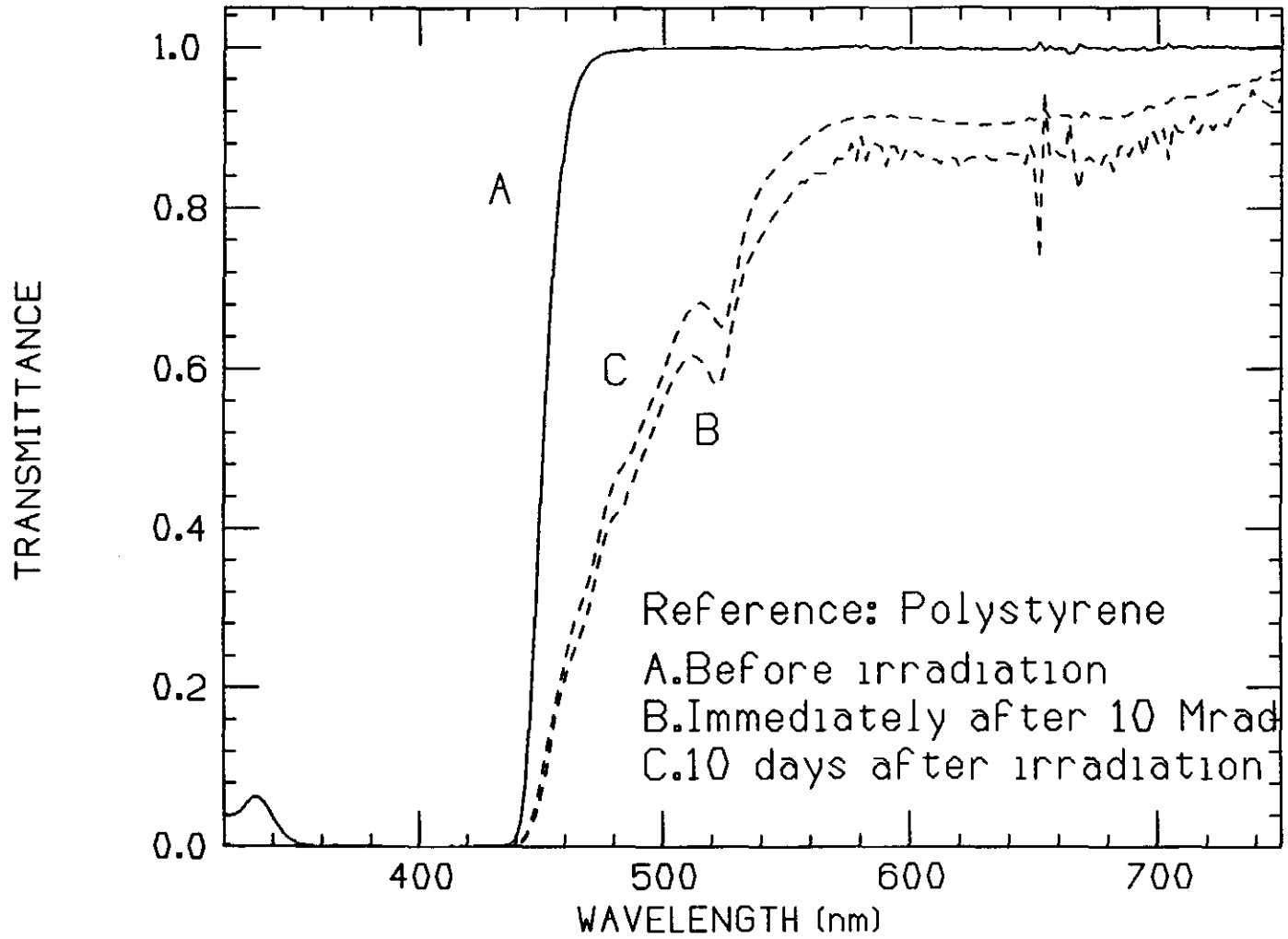

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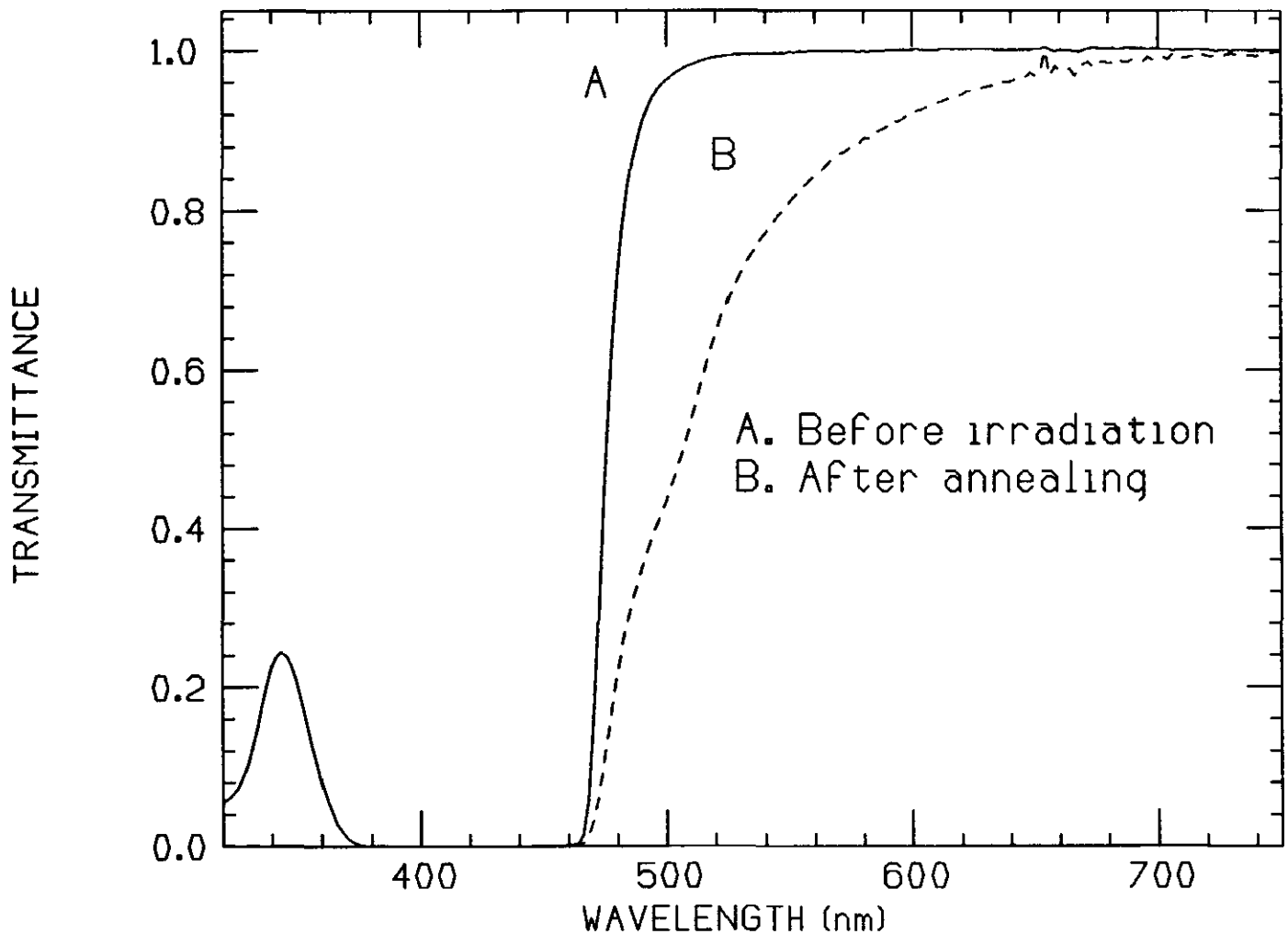

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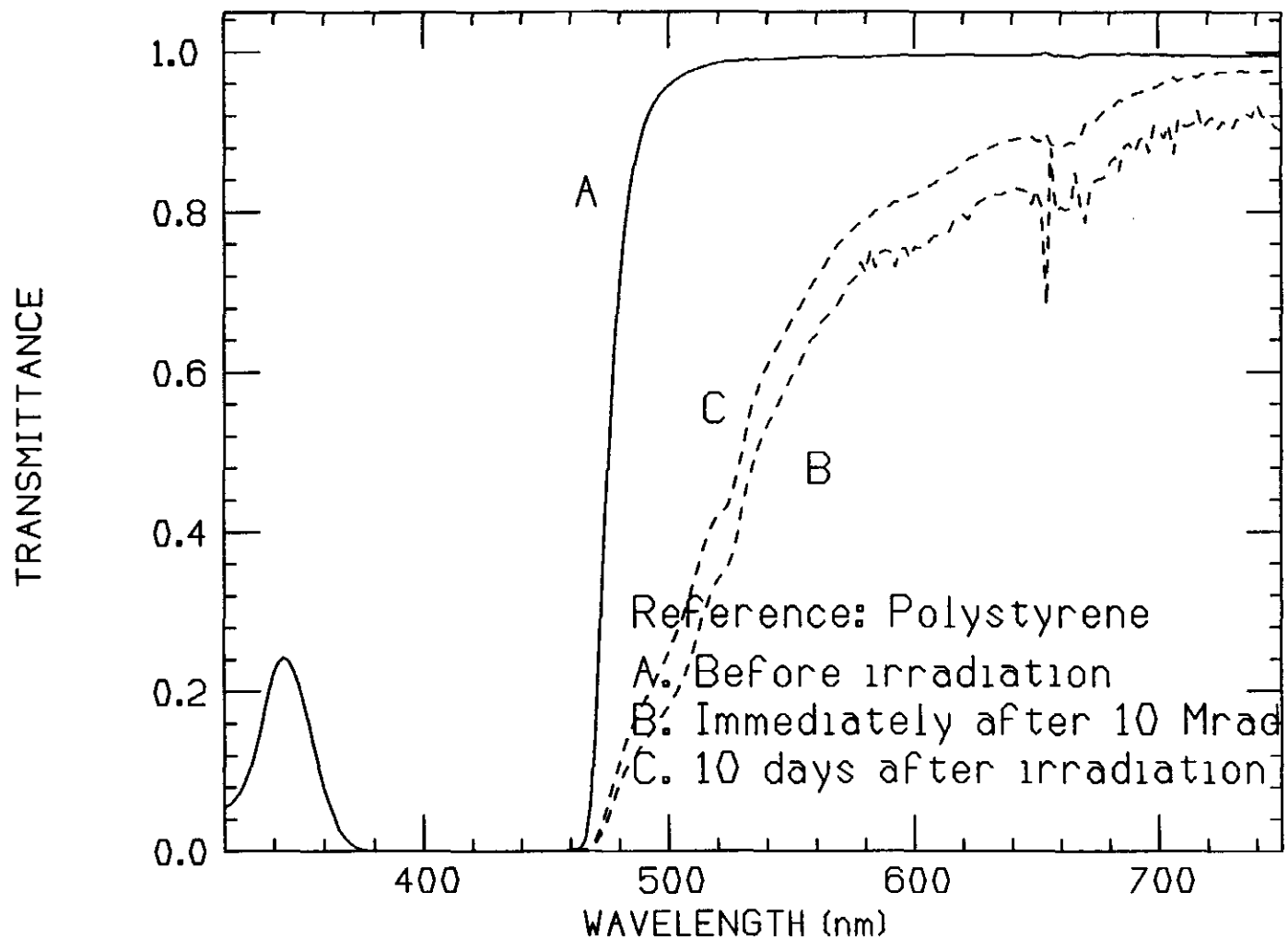

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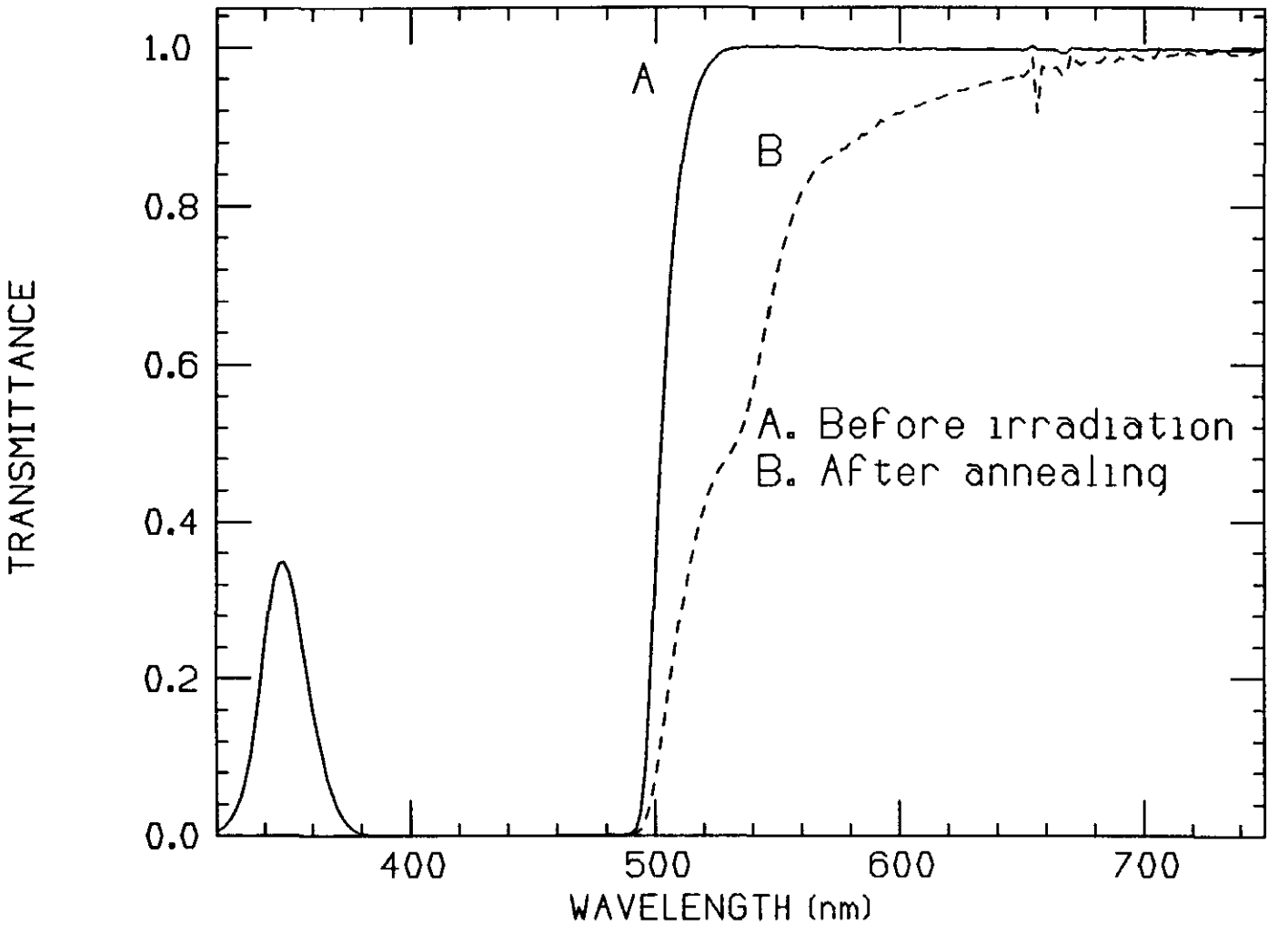

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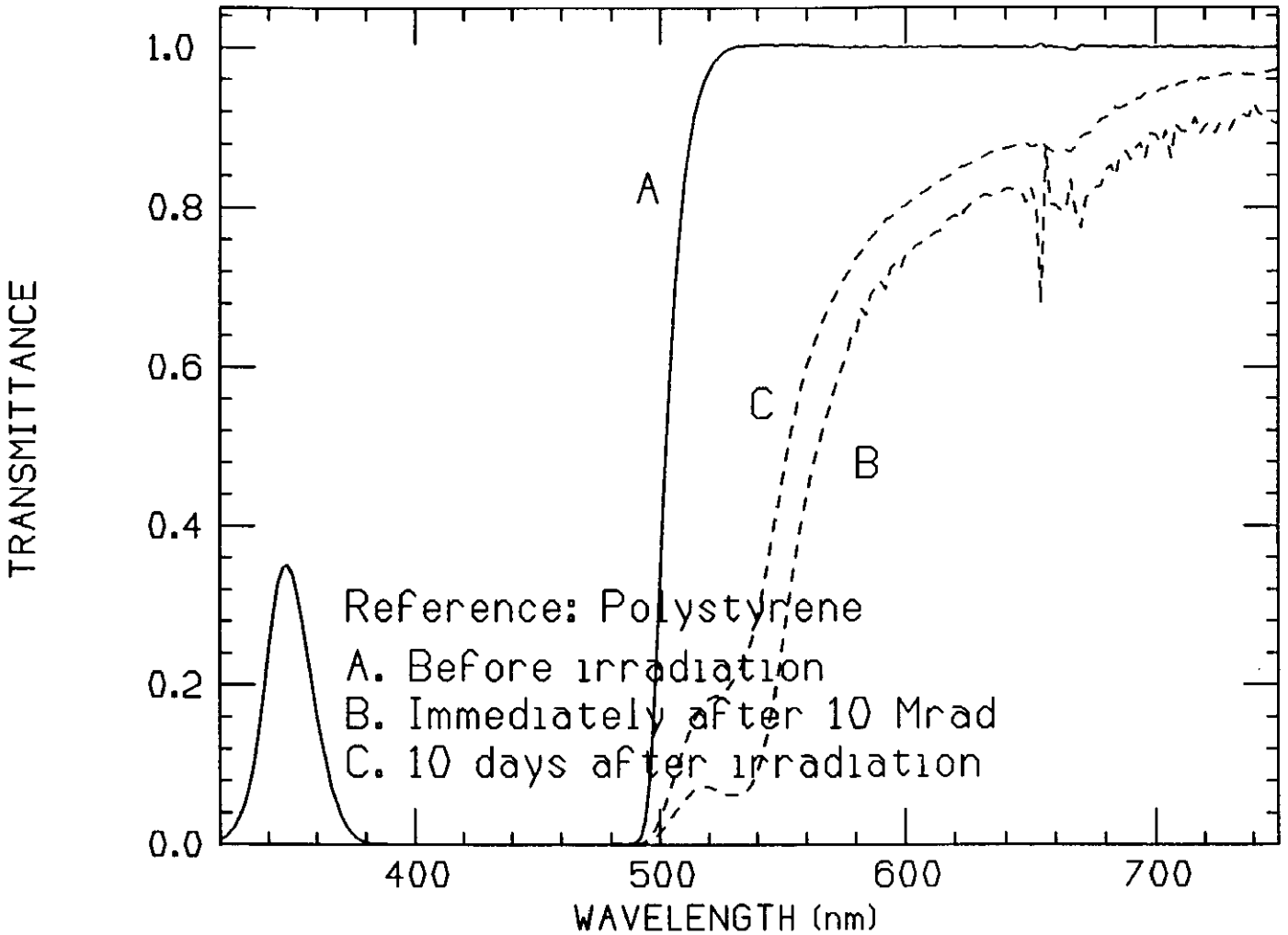

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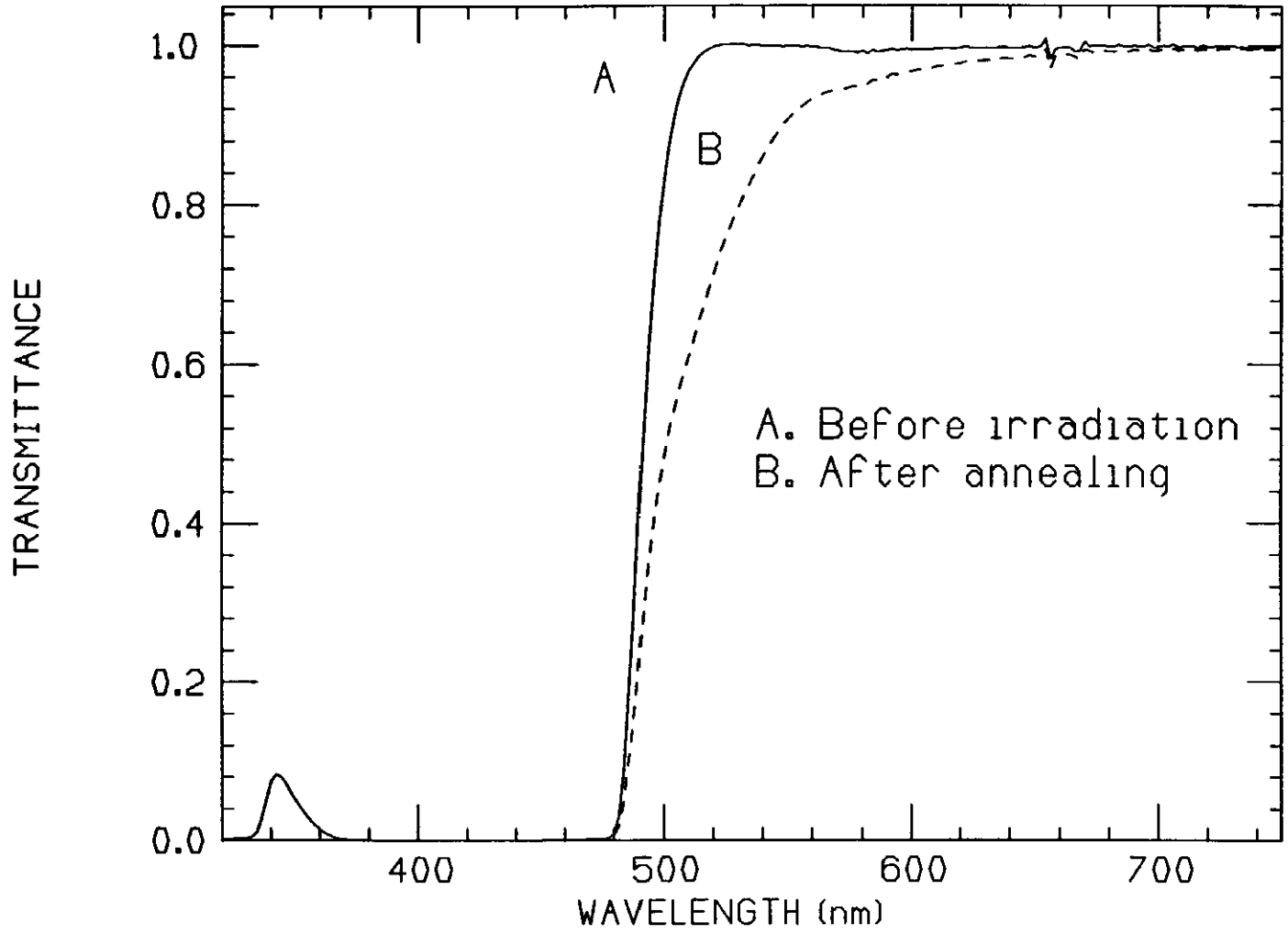
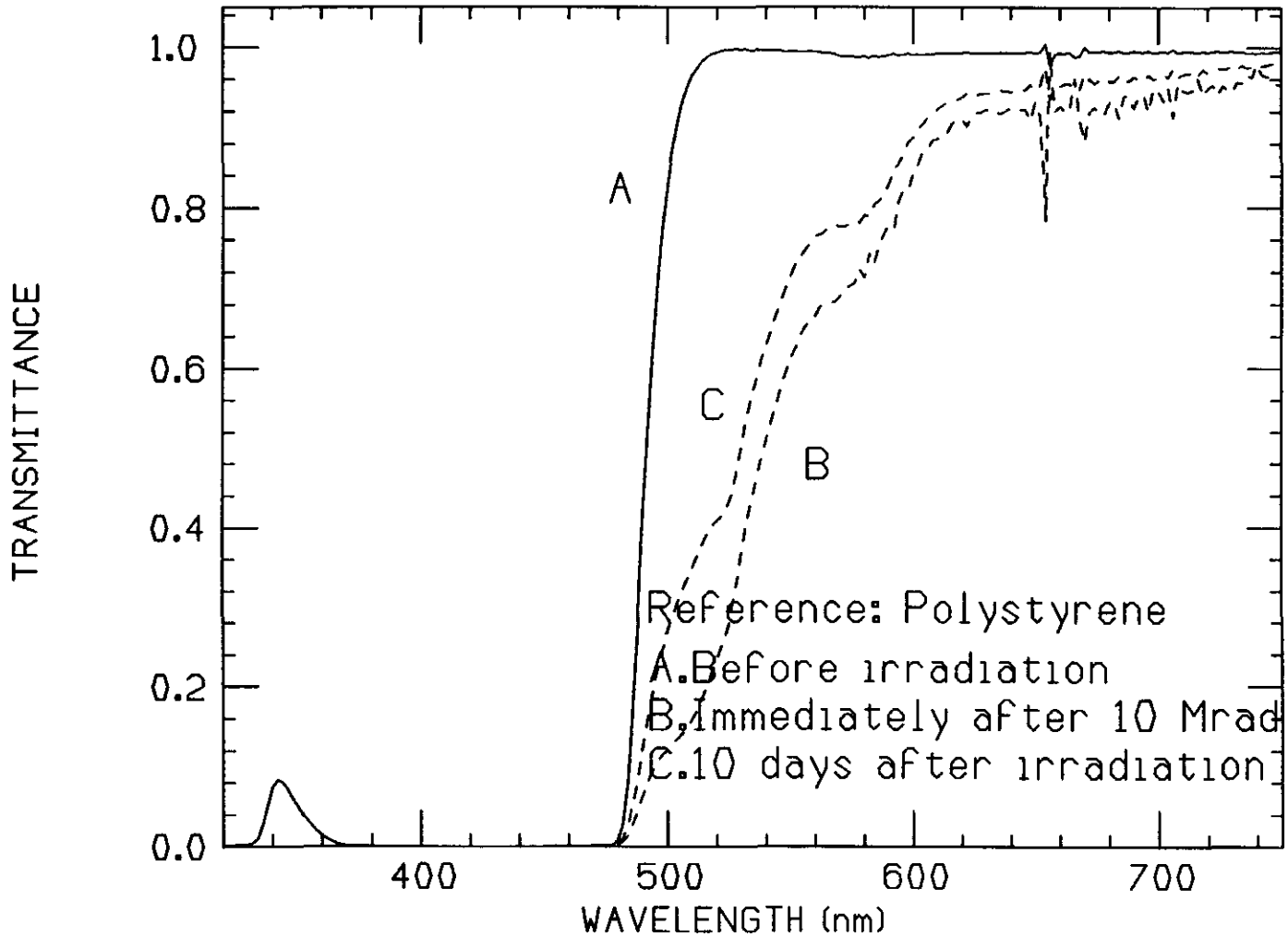
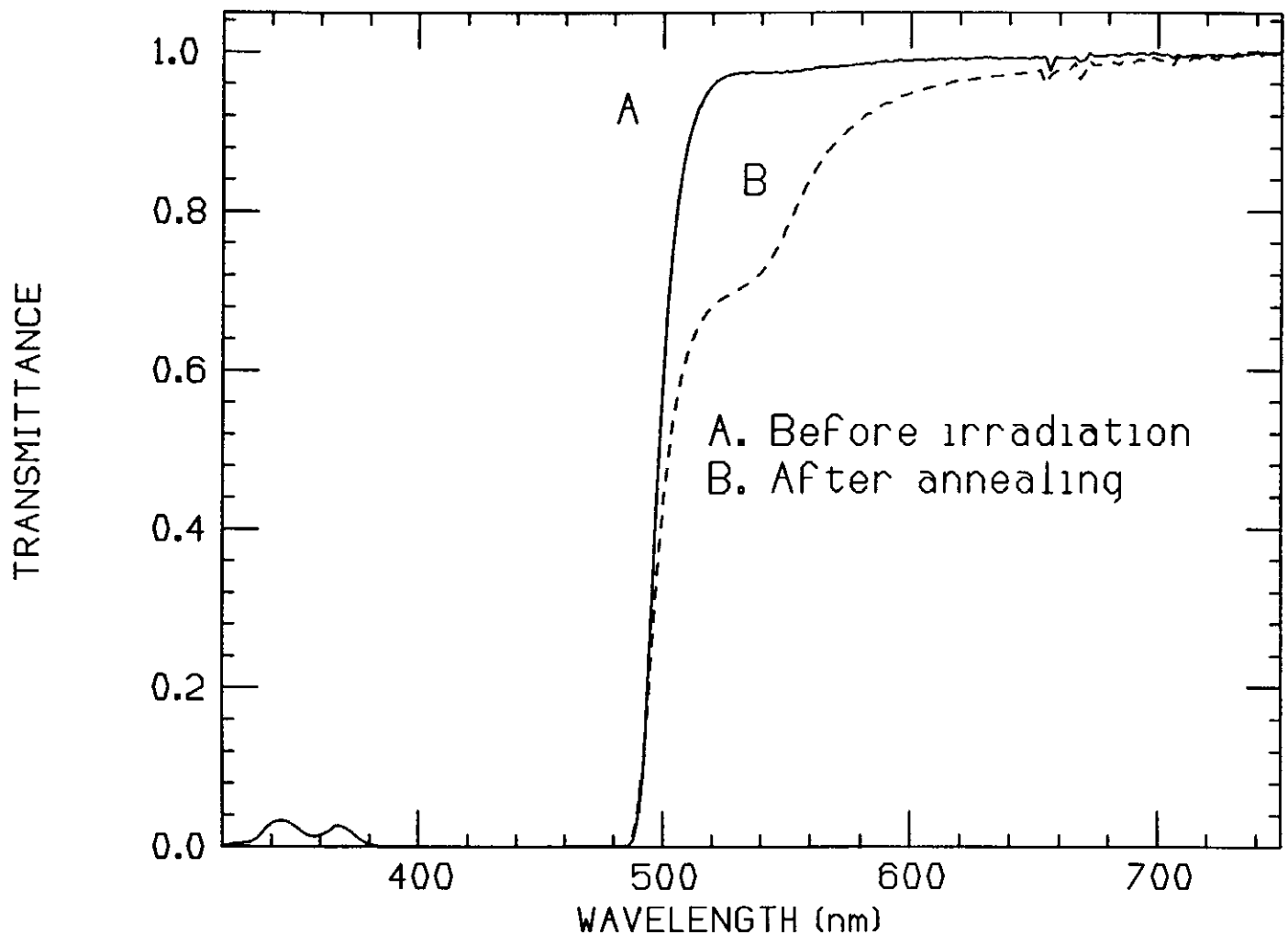


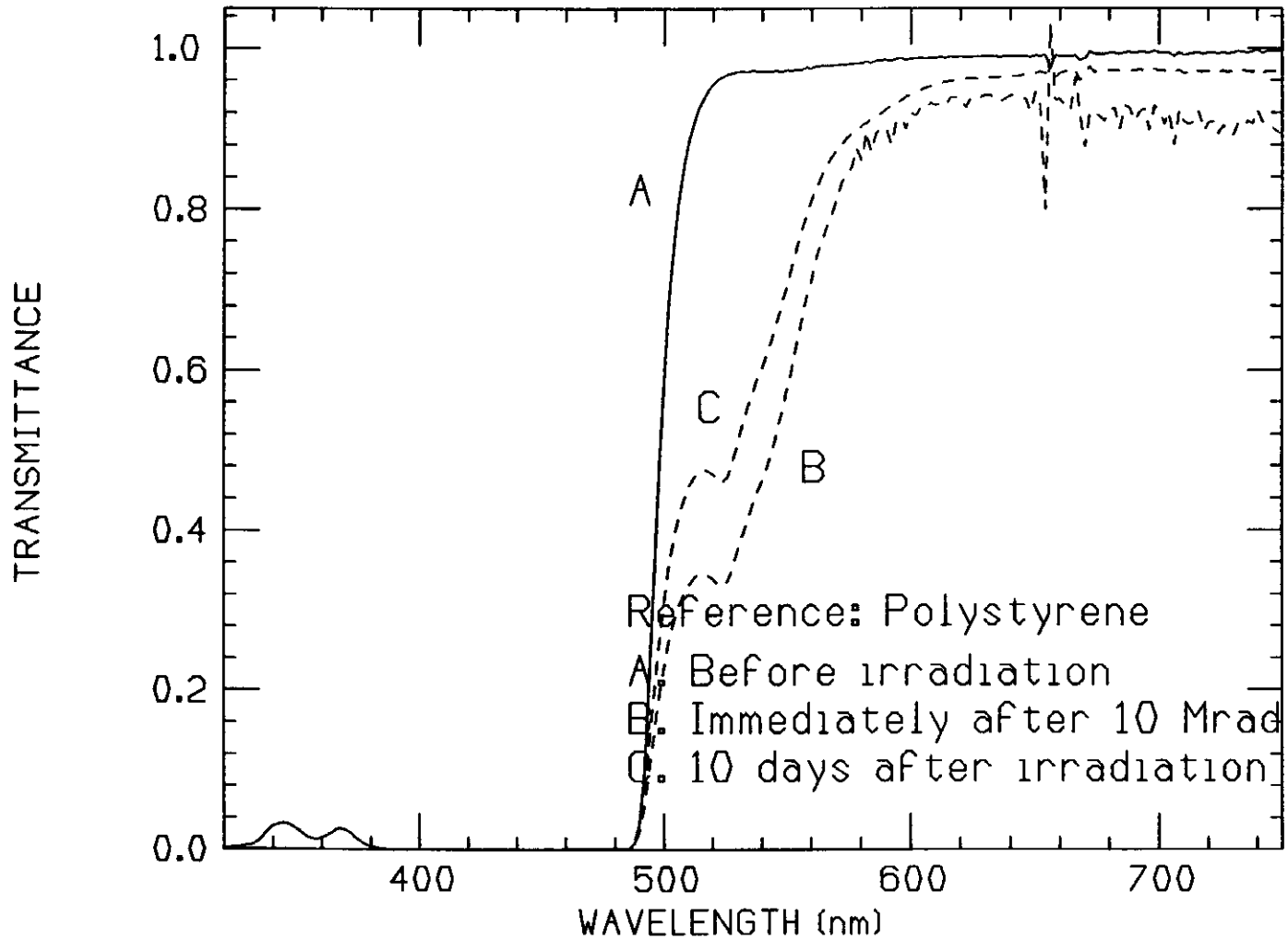
0.02% C535 - HIGH DOSE RATE IRRADIATION IN AIR



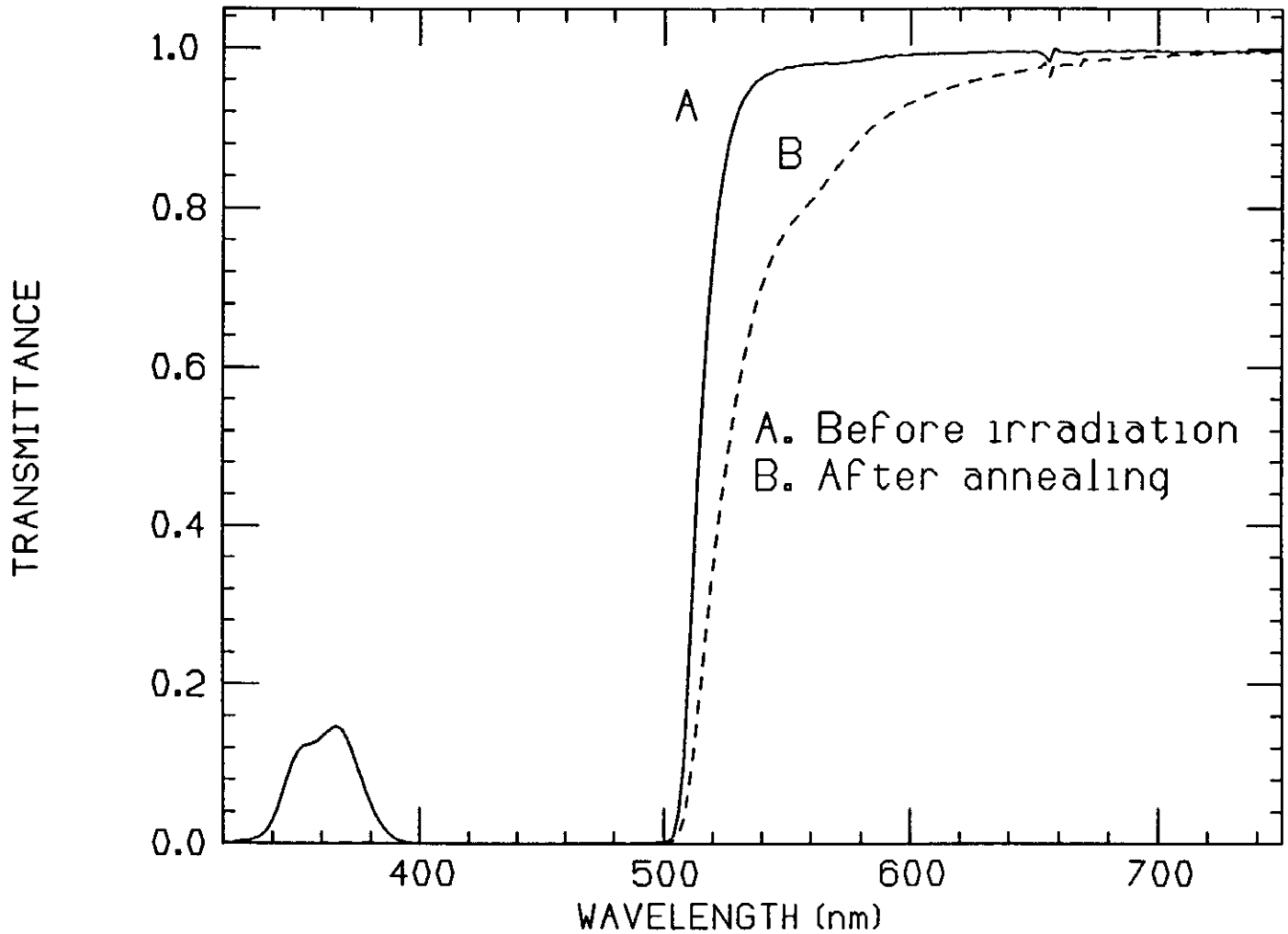
0.02% C540 - HIGH DOSE RATE IRRADIATION IN AIR



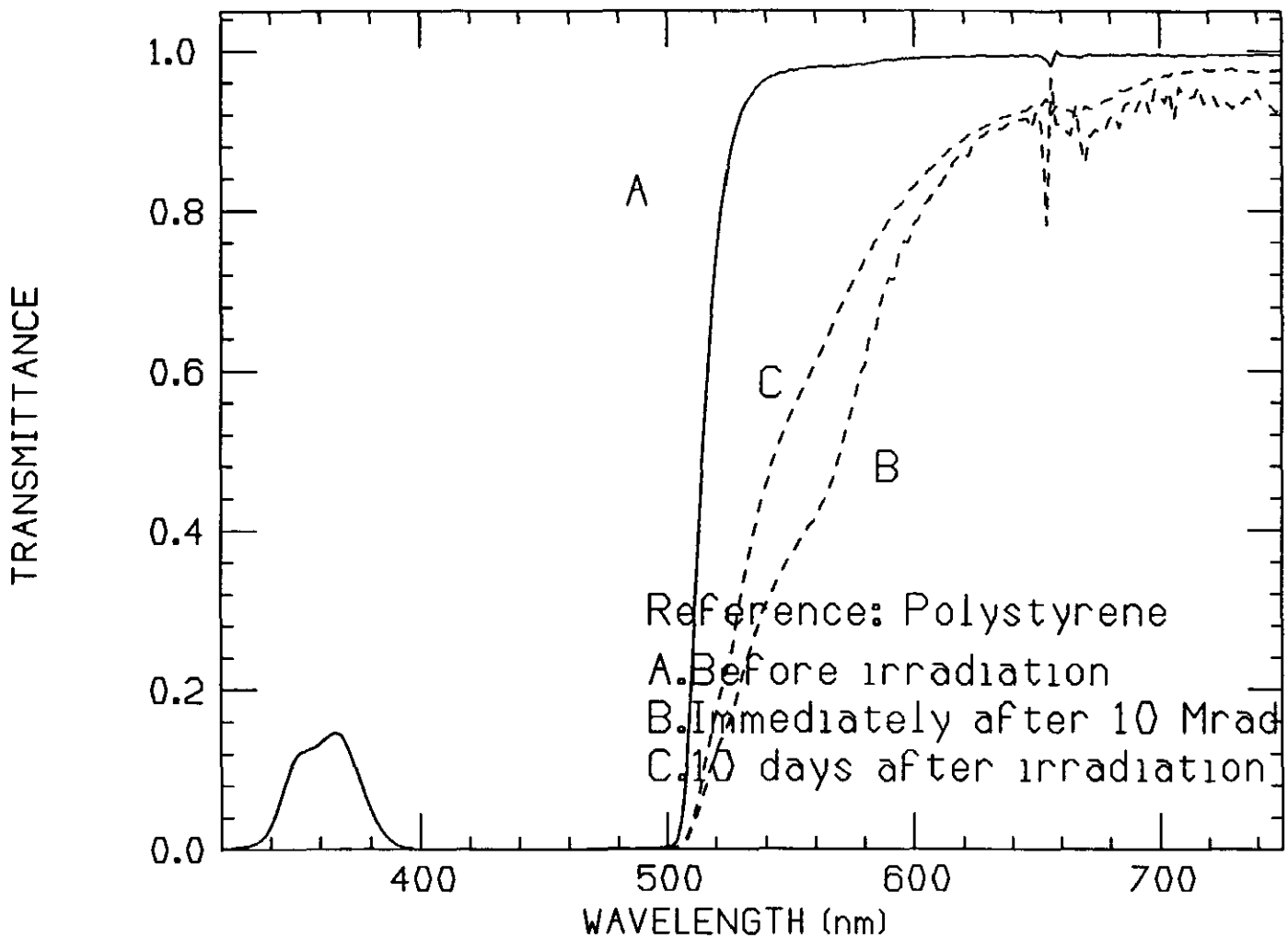
0.02% C540 - HIGH DOSE RATE IRRADIATION IN AIR



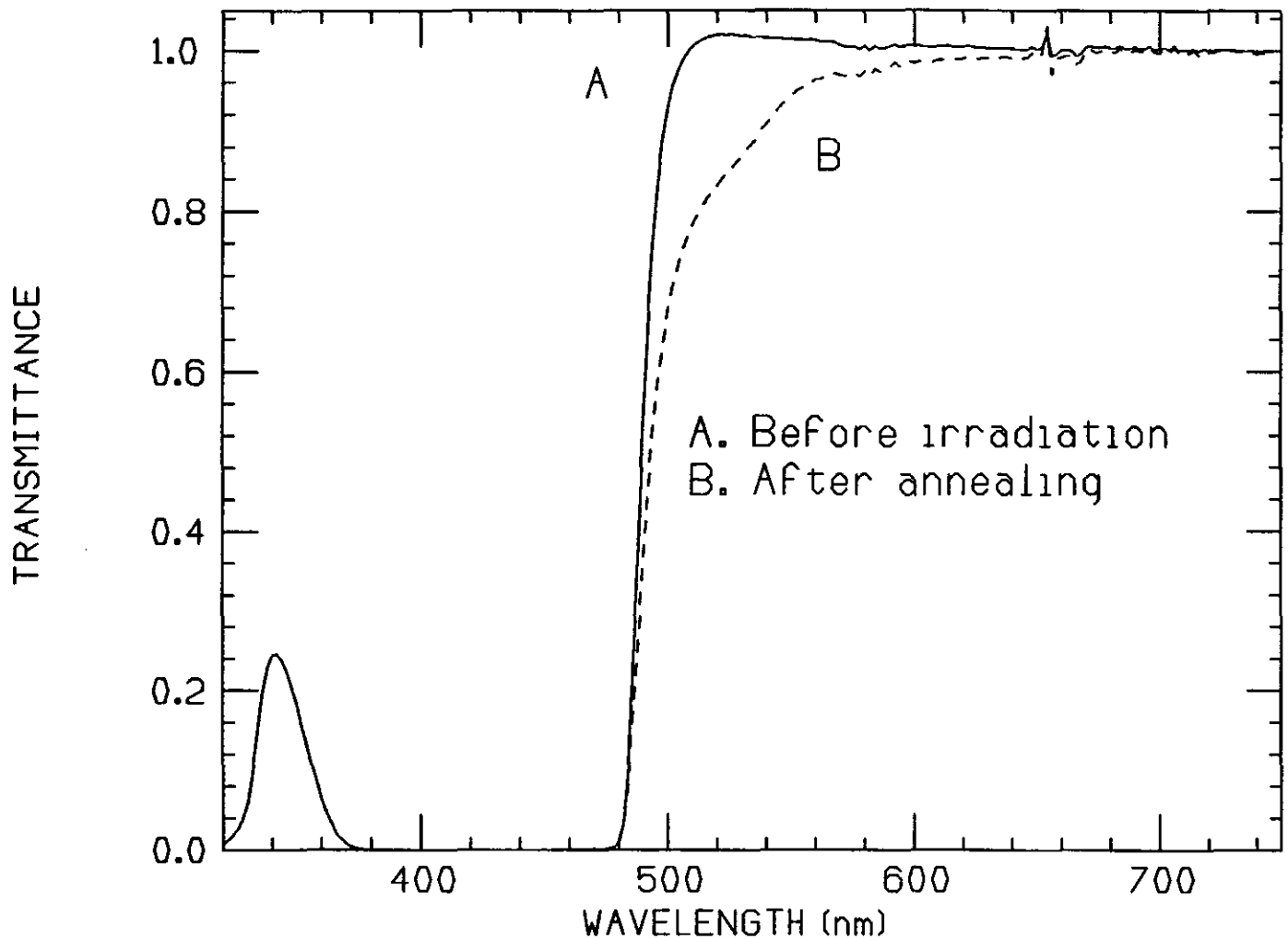
0.02% C545 - HIGH DOSE RATE IRRADIATION IN AIR



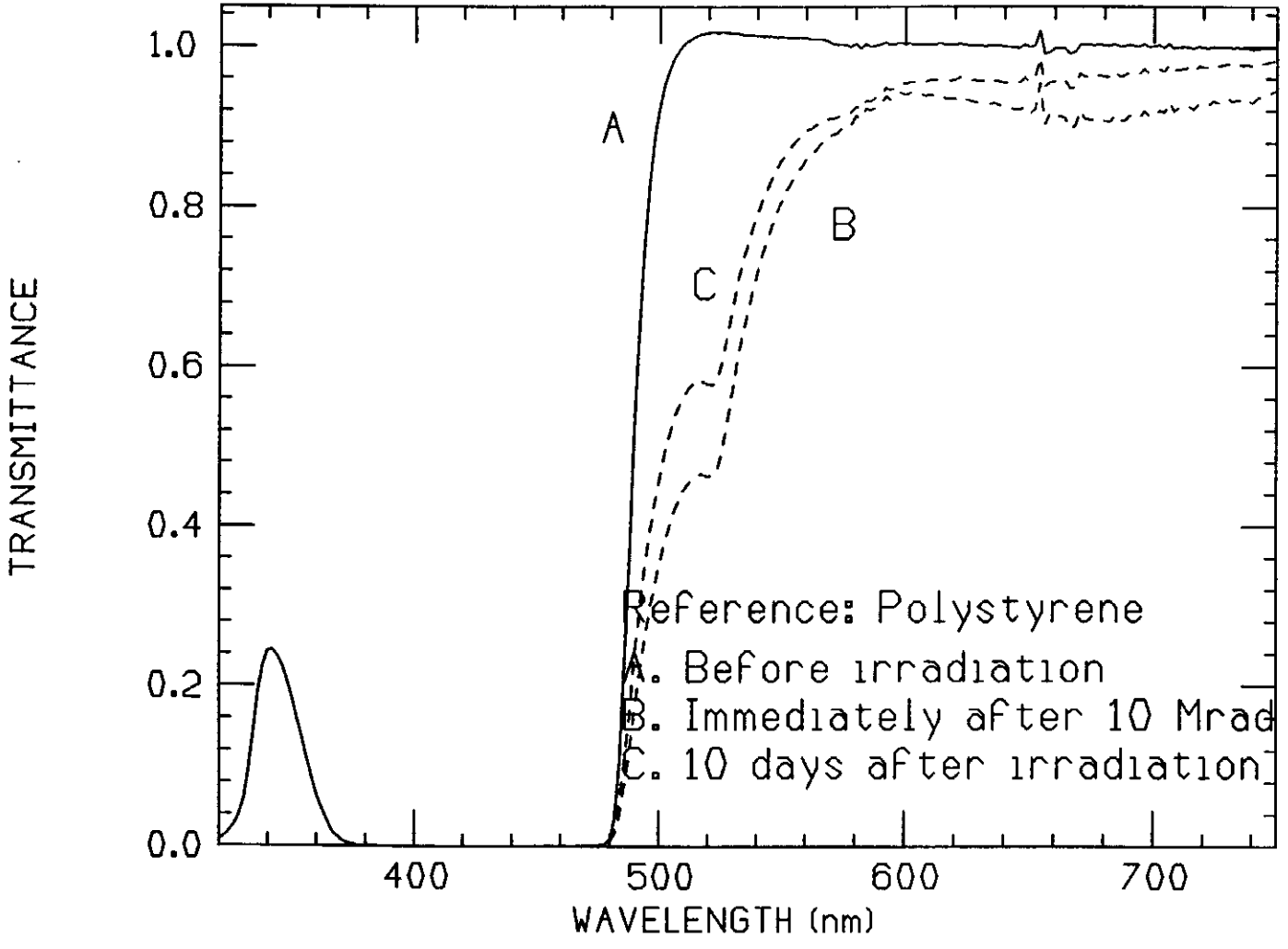
0.02% C545 - HIGH DOSE RATE IRRADIATION IN AIR



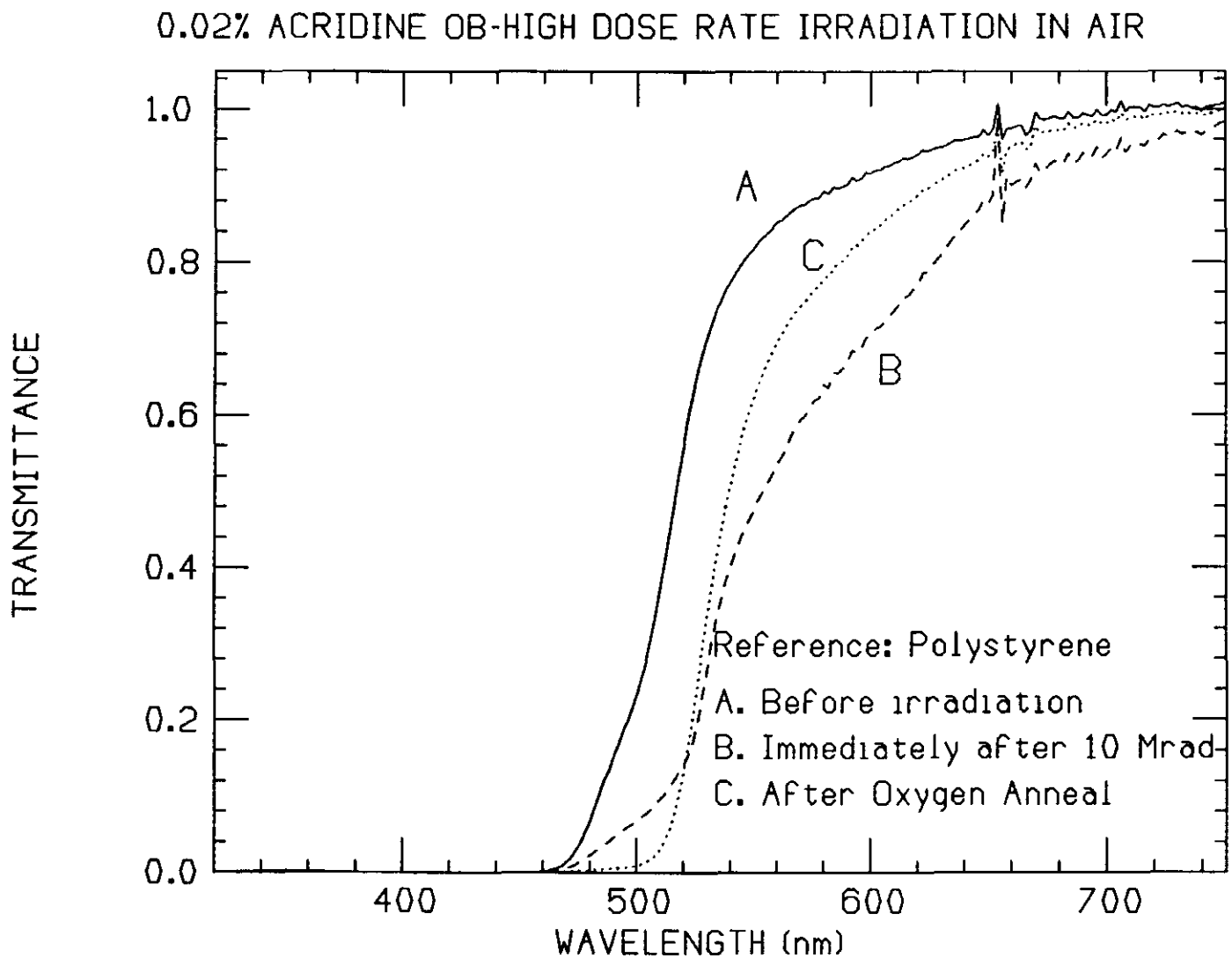
0.02% LPY - HIGH DOSE RATE IRRADIATION IN AIR



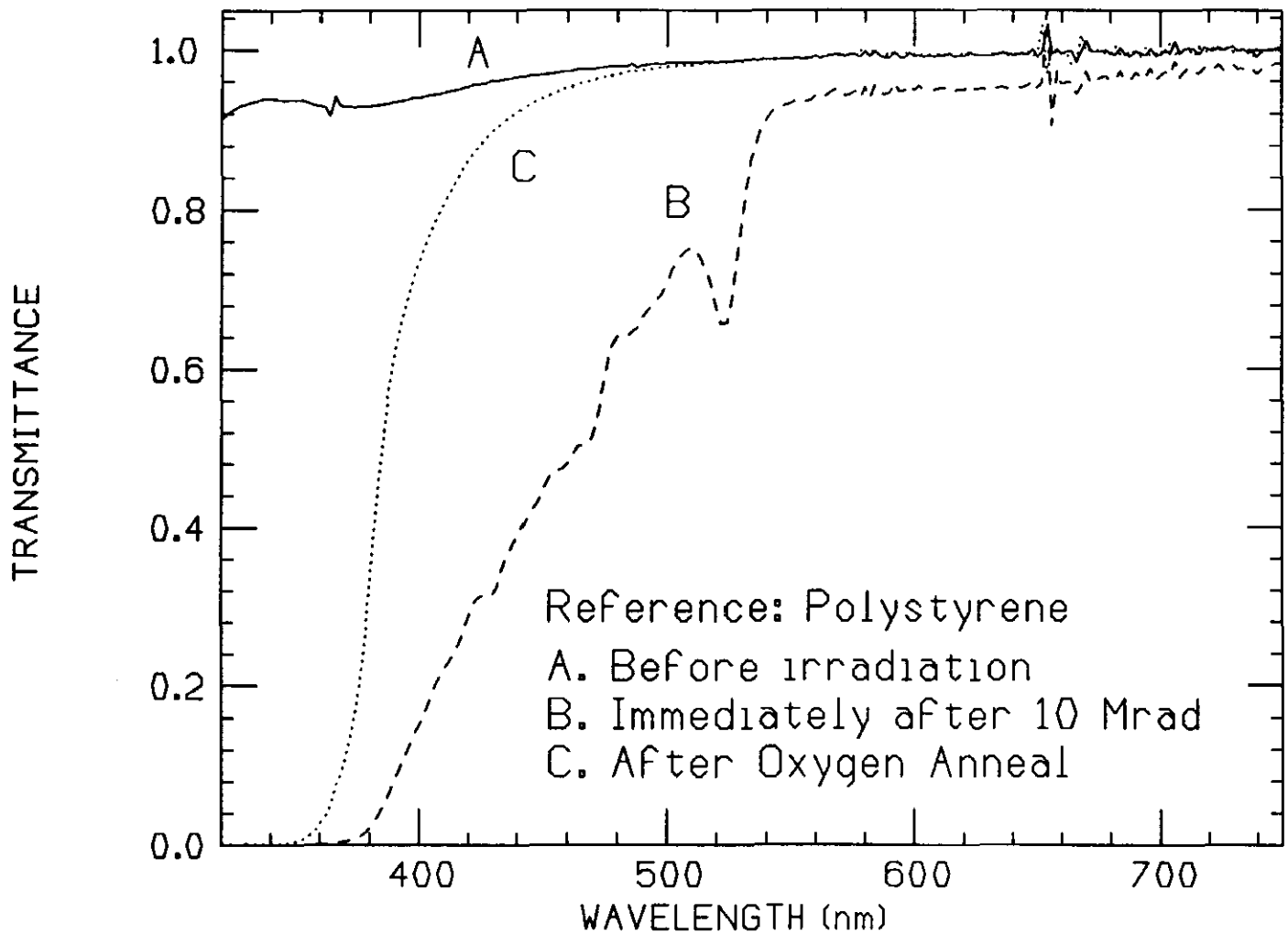
0.02% LPY - HIGH DOSE RATE IRRADIATION IN AIR



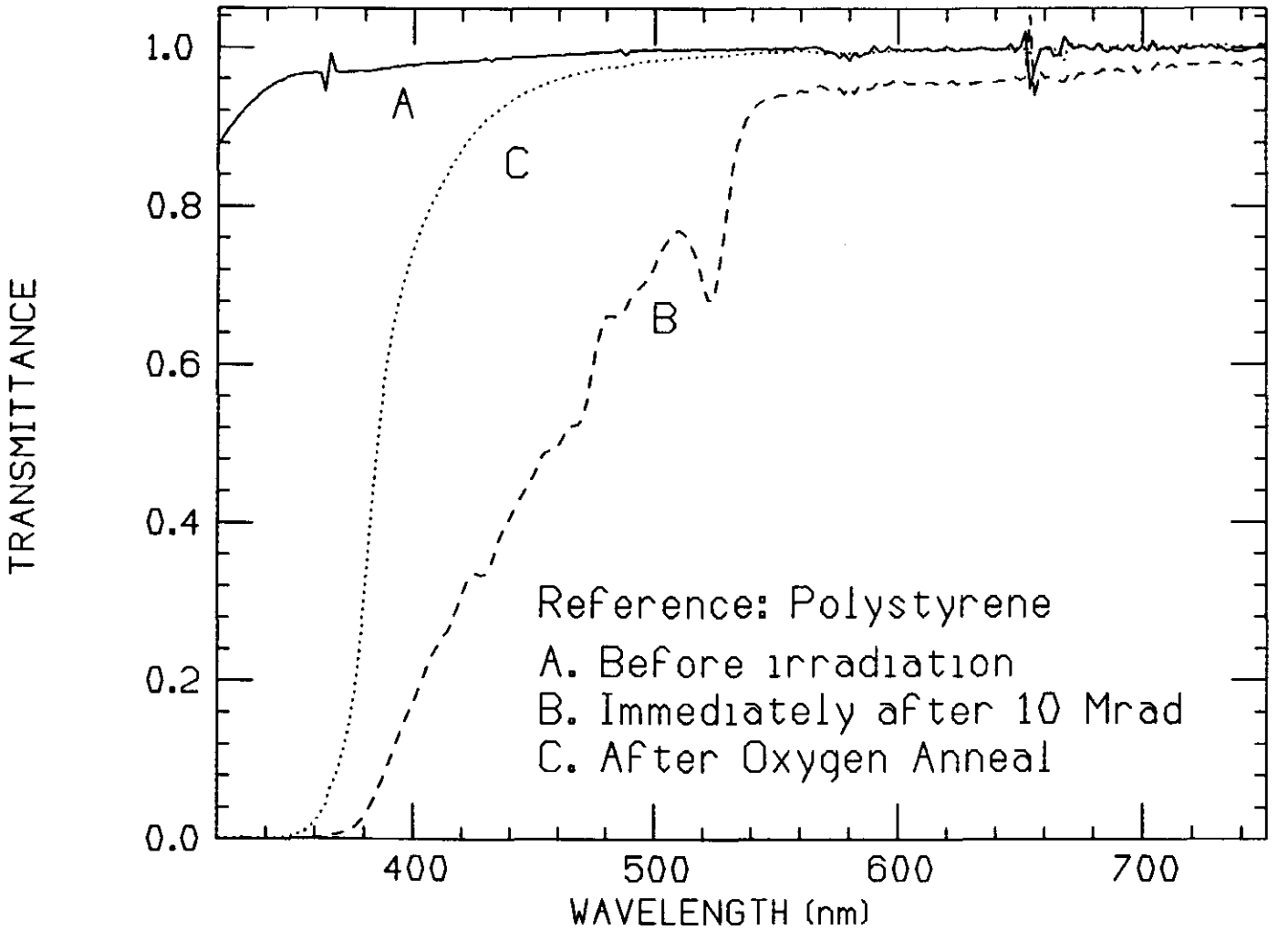
PART II
RADIATION DAMAGE SET #22


0.02% ACRIDINE OB-HIGH DOSE RATE IRRADIATION IN AIR
TRANSMITTANCE
1.0
0.8
0.6
0.4
0.2
0.0
400
500
600
700
WAVELENGTH (nm)
A
B
C
Reference: Polystyrene
A. Before irradiation
B. Immediately after 10 Mrad
C. After Oxygen Anneal

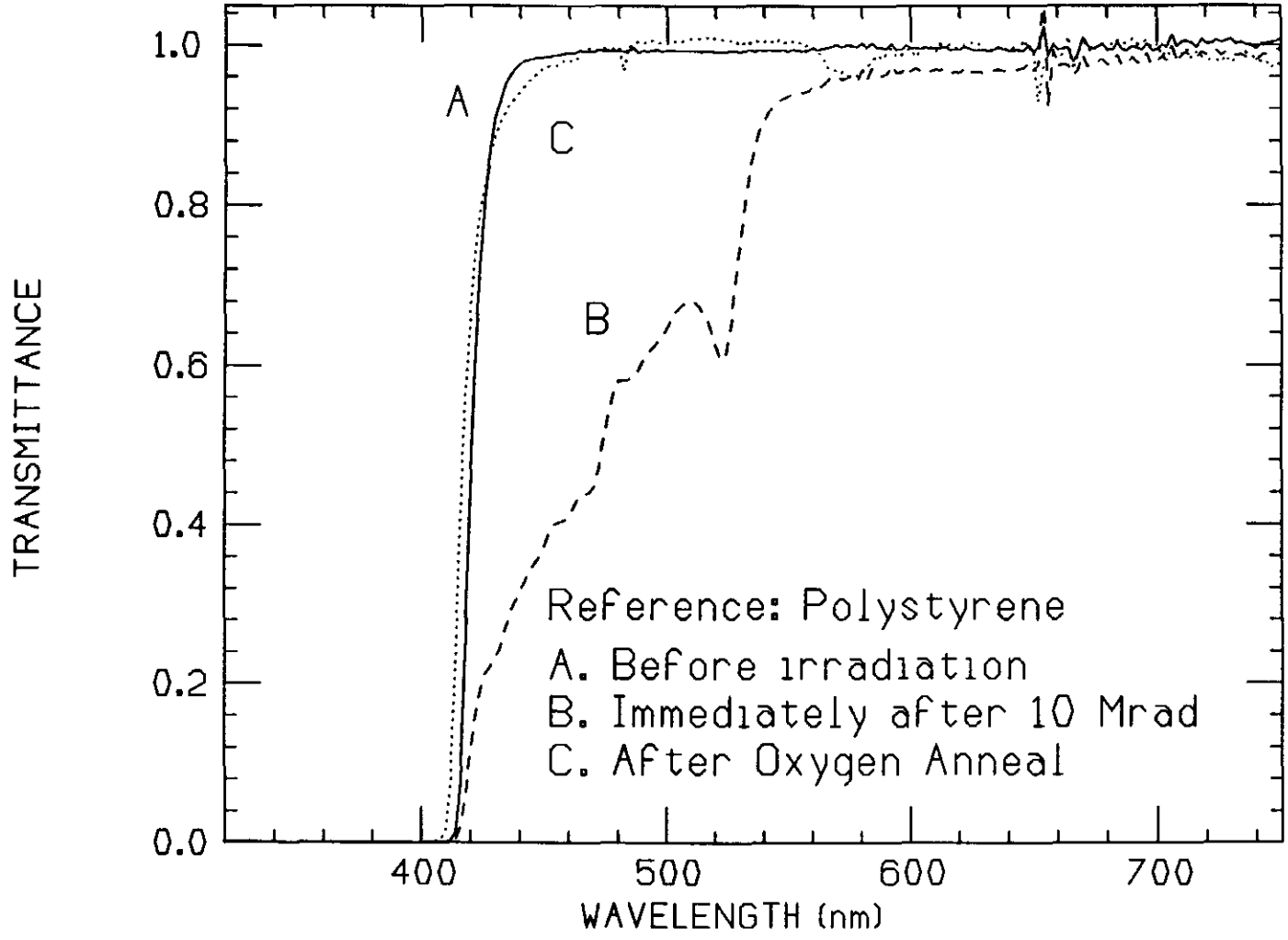
0.02% ACRIDINE Y -HIGH DOSE RATE IRRADIATION IN AIR



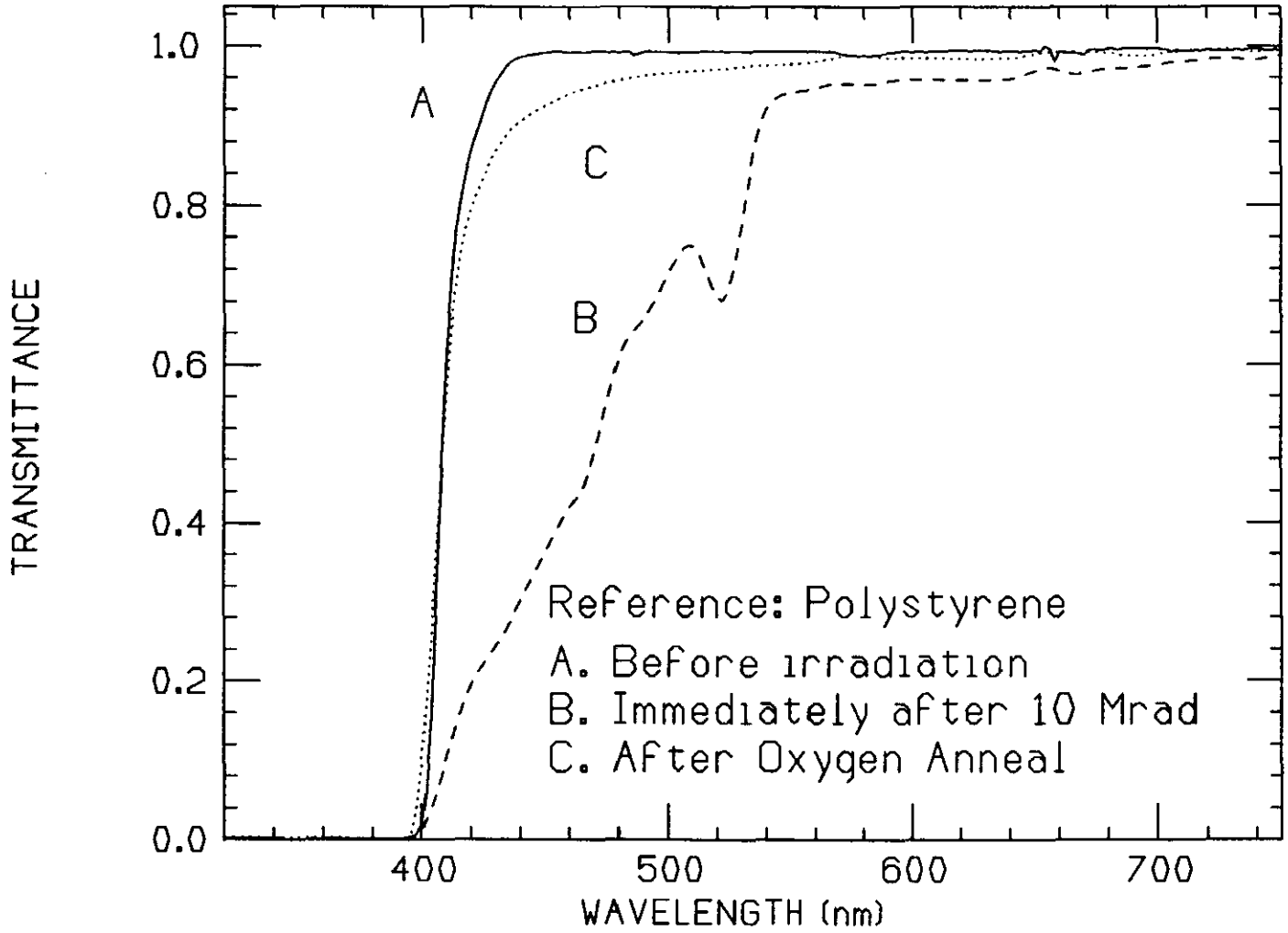
0.02% ACRIFLAVIN -HIGH DOSE RATE IRRADIATION IN AIR



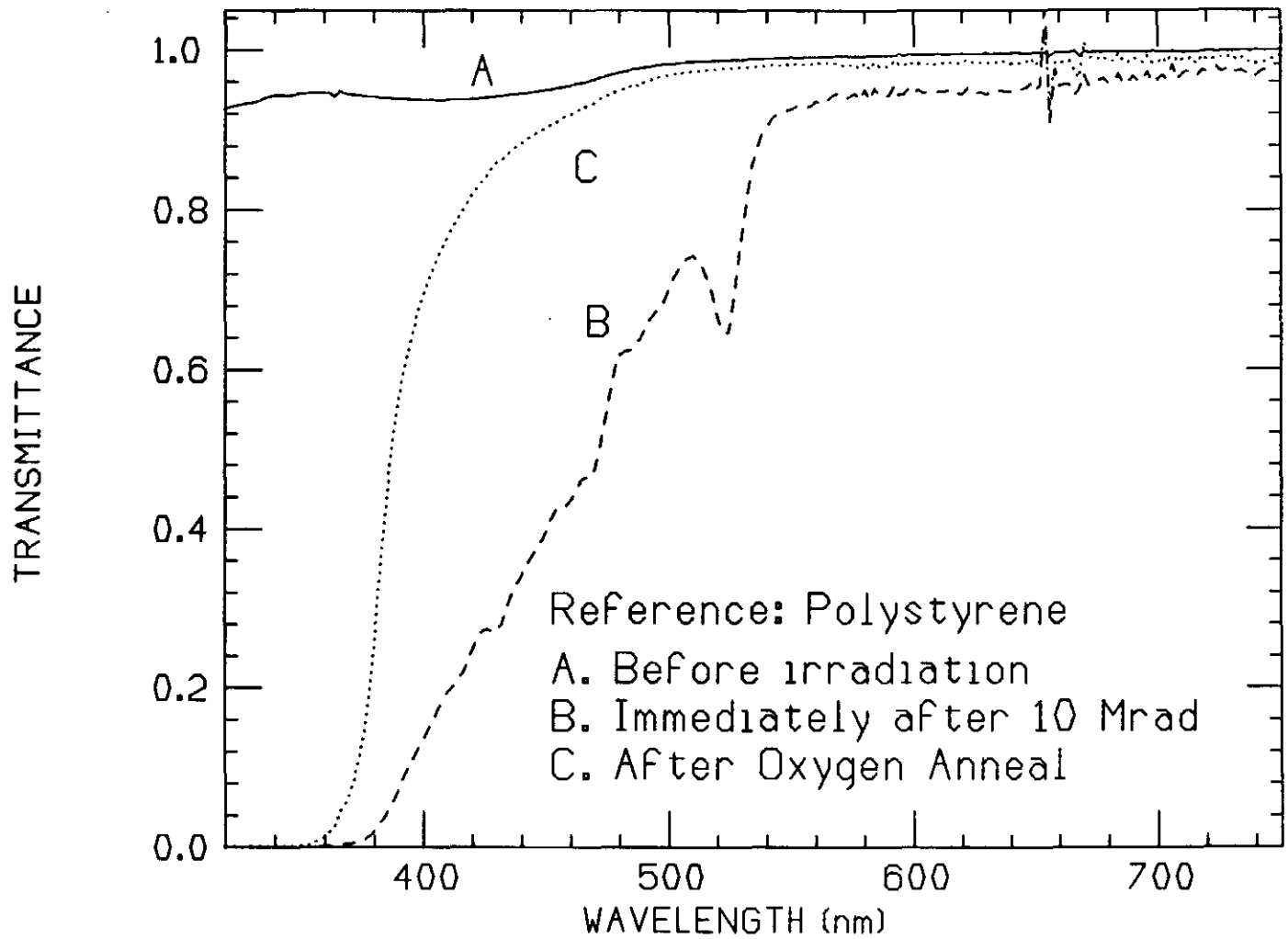
0.02% BBOT - HIGH DOSE RATE IRRADIATION IN AIR

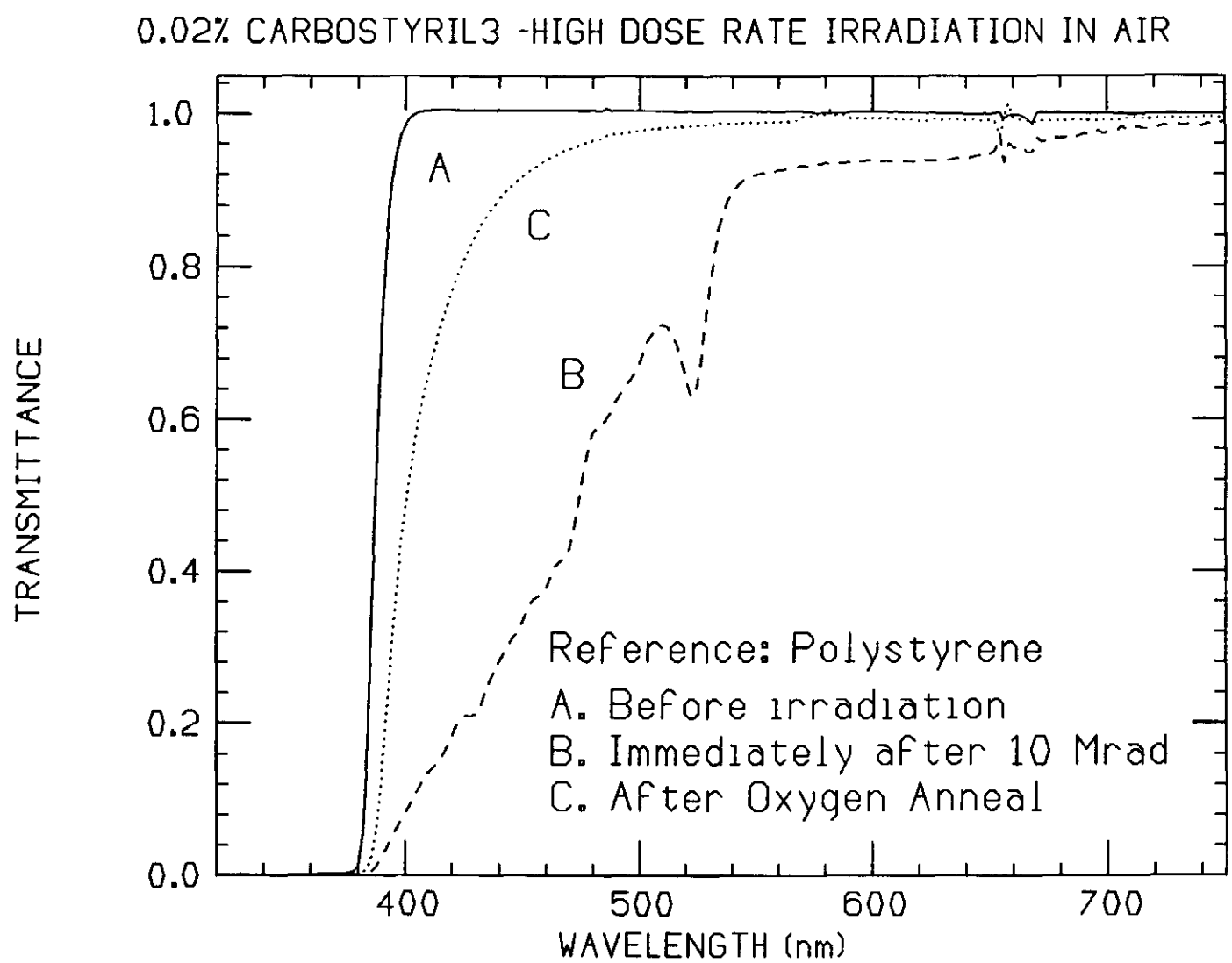


0.02% bis-MSB - HIGH DOSE RATE IRRADIATION IN AIR

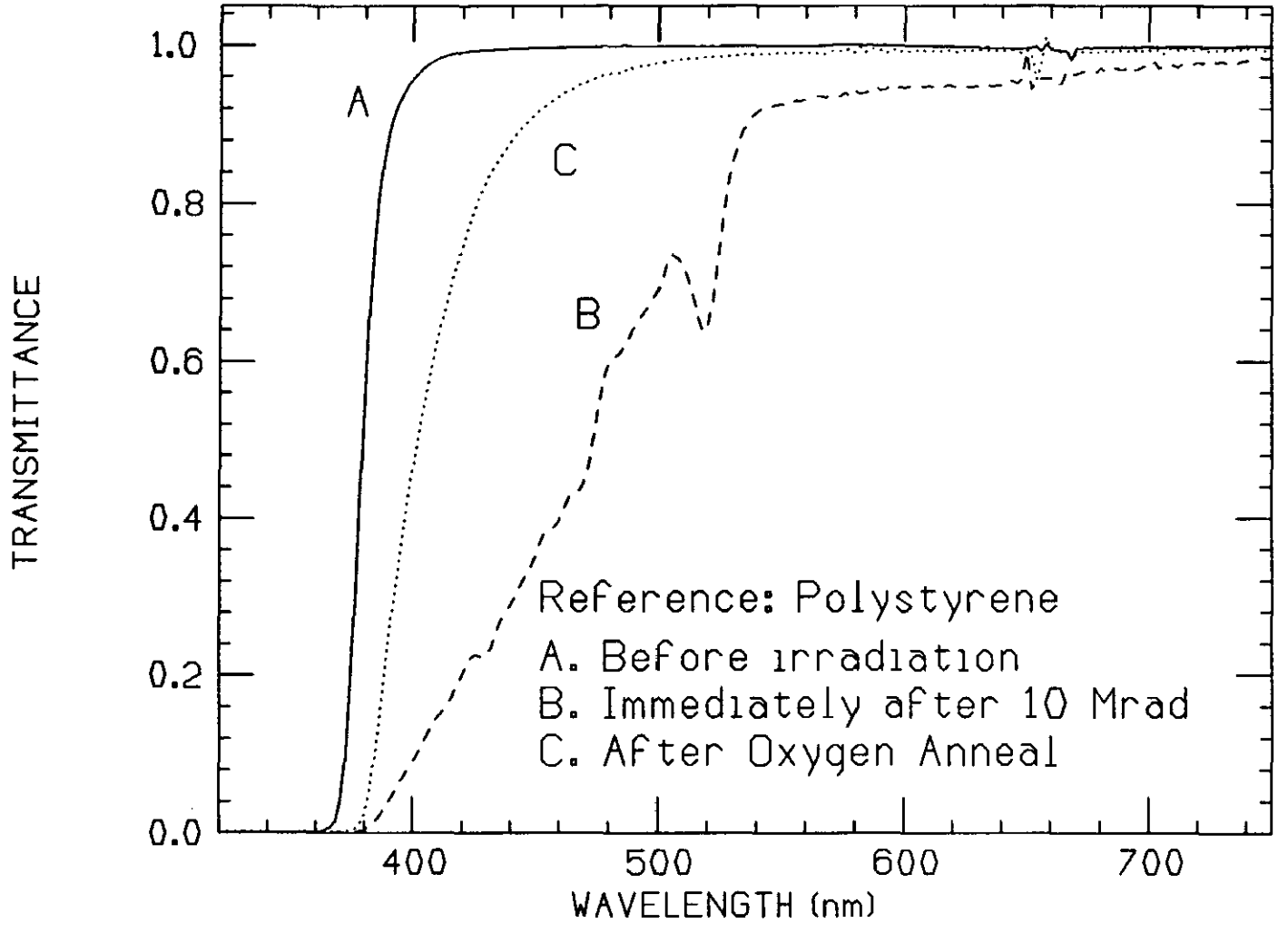


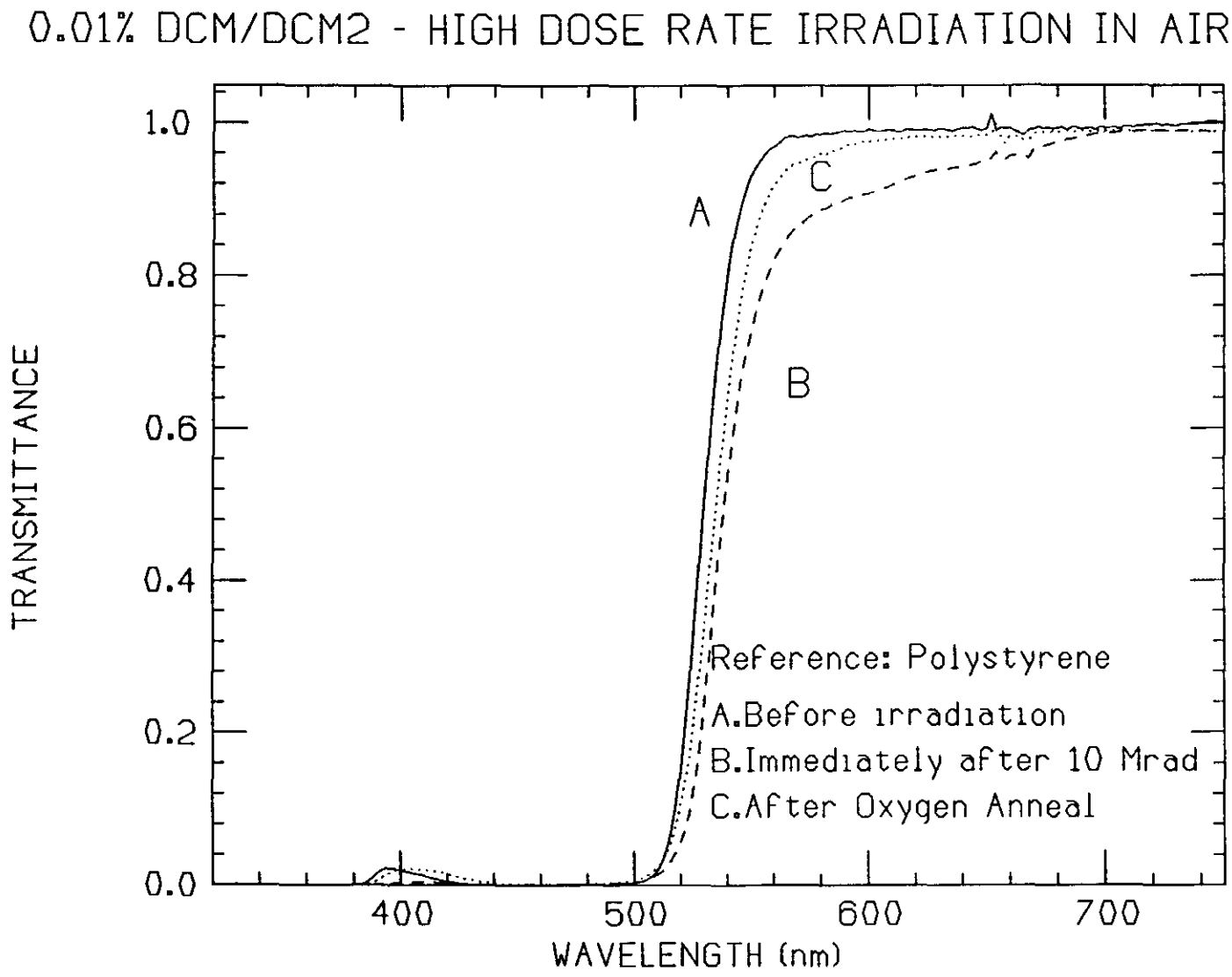
0.02% BSFL - HIGH DOSE RATE IRRADIATION IN AIR



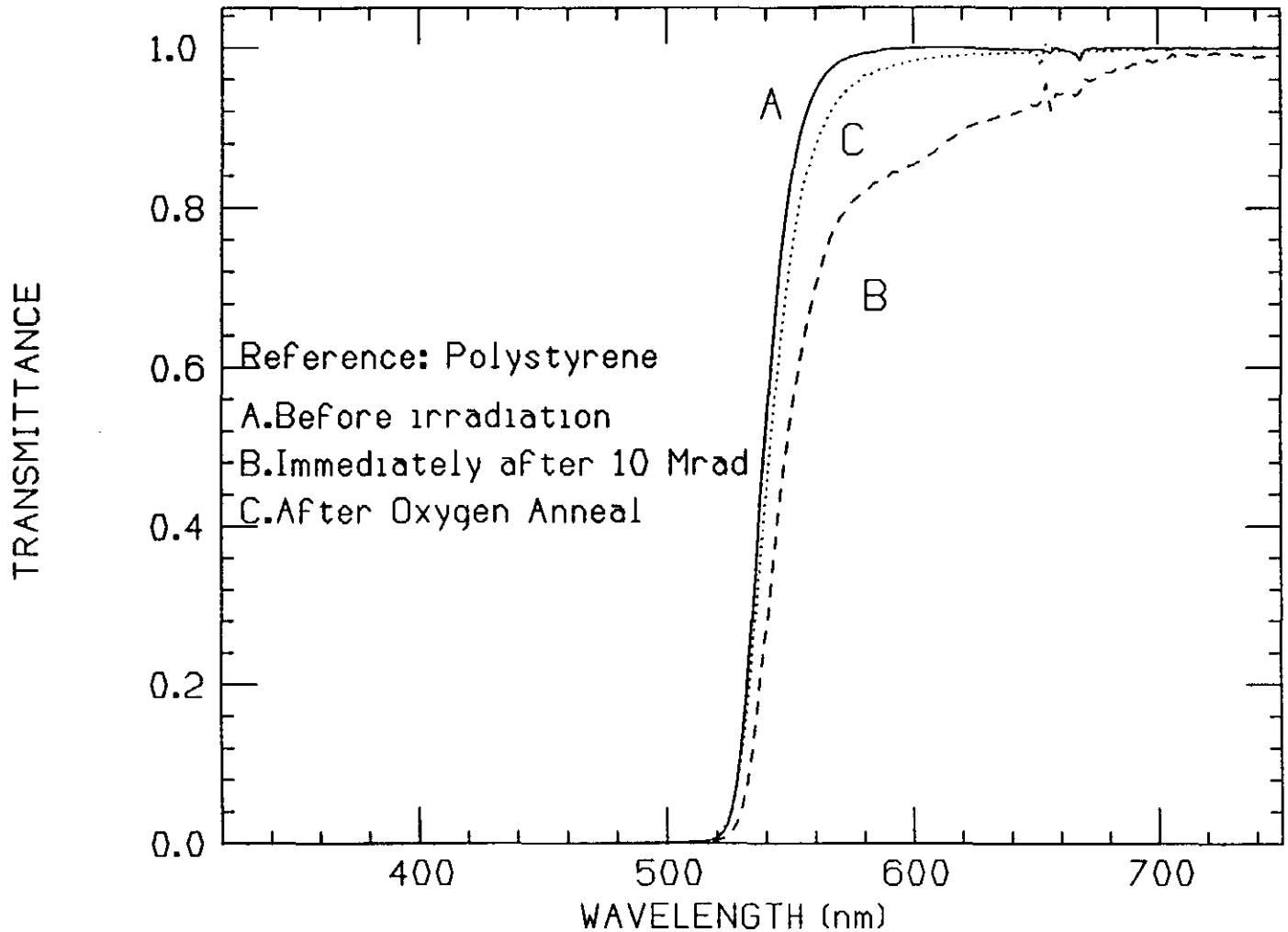

0.02% CARBOSTYRIL3 -HIGH DOSE RATE IRRADIATION IN AIR
TRANSMITTANCE
1.0
0.8
0.6
0.4
0.2
0.0
400
500
600
700
WAVELENGTH (nm)
A
B
C
Reference: Polystyrene
A. Before irradiation
B. Immediately after 10 Mrad
C. After Oxygen Anneal

0.02% CBSTY 124 - HIGH DOSE RATE IRRADIATION IN AIR

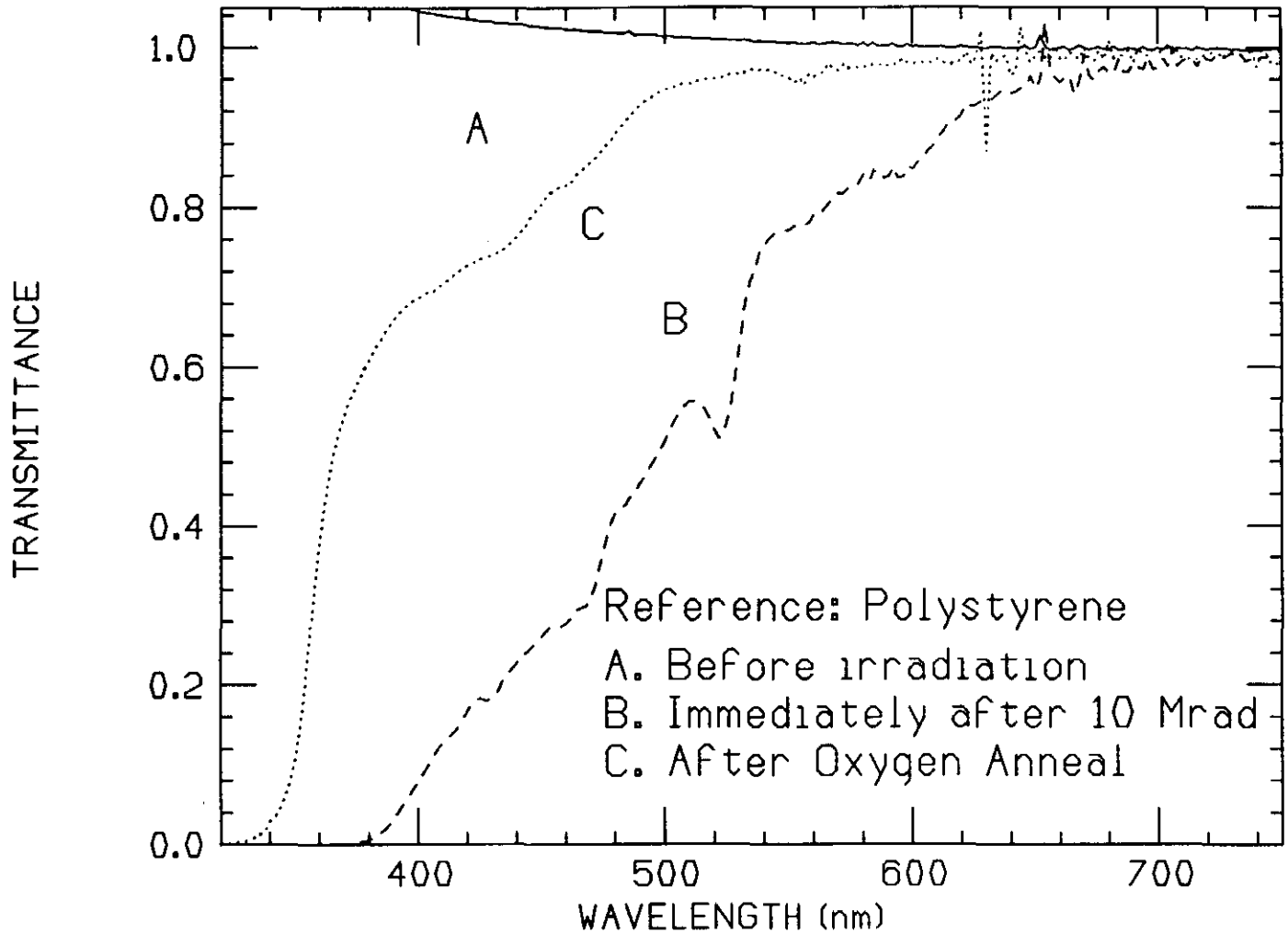



0.01% DCM/DCM2 - HIGH DOSE RATE IRRADIATION IN AIR
TRANSMITTANCE
1.0
0.8
0.6
0.4
0.2
0.0
400
500
600
700
WAVELENGTH (nm)
A
B
C
Reference: Polystyrene
A.Before irradiation
B.Immediately after 10 Mrad
C.After Oxygen Anneal

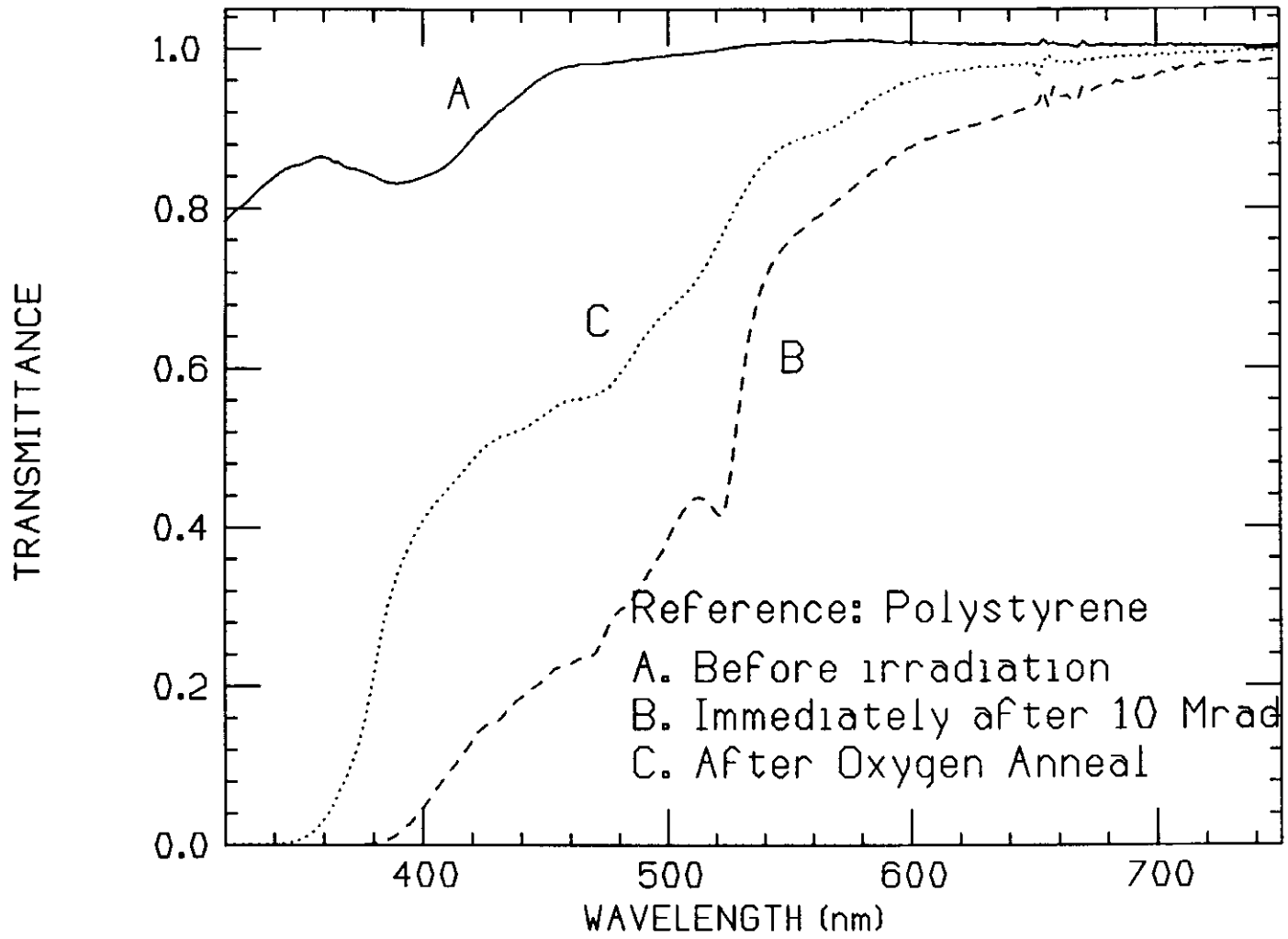
0.02% DCM/DCM2 - HIGH DOSE RATE IRRADIATION IN AIR

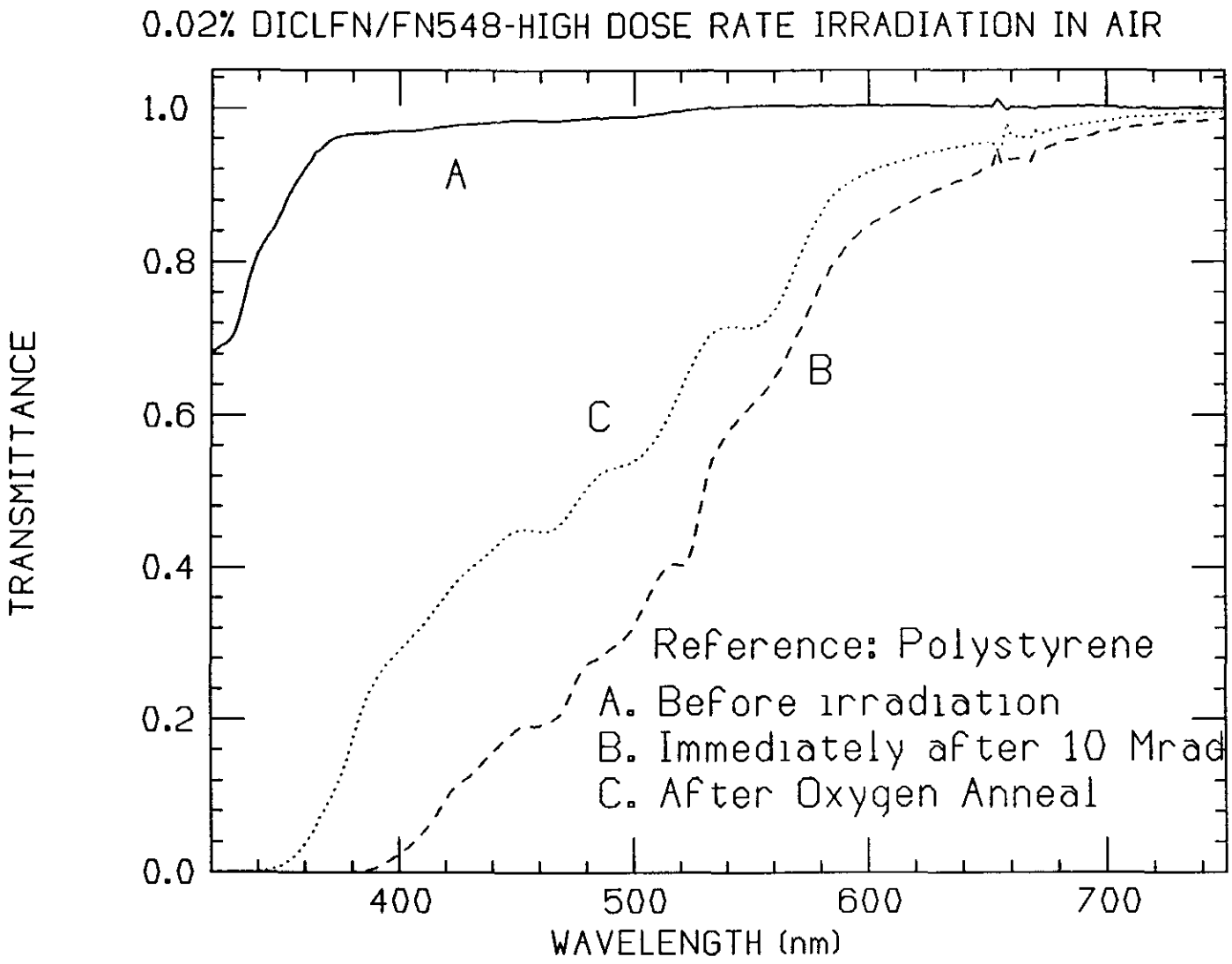


0.02% DIACFN - HIGH DOSE RATE IRRADIATION IN AIR

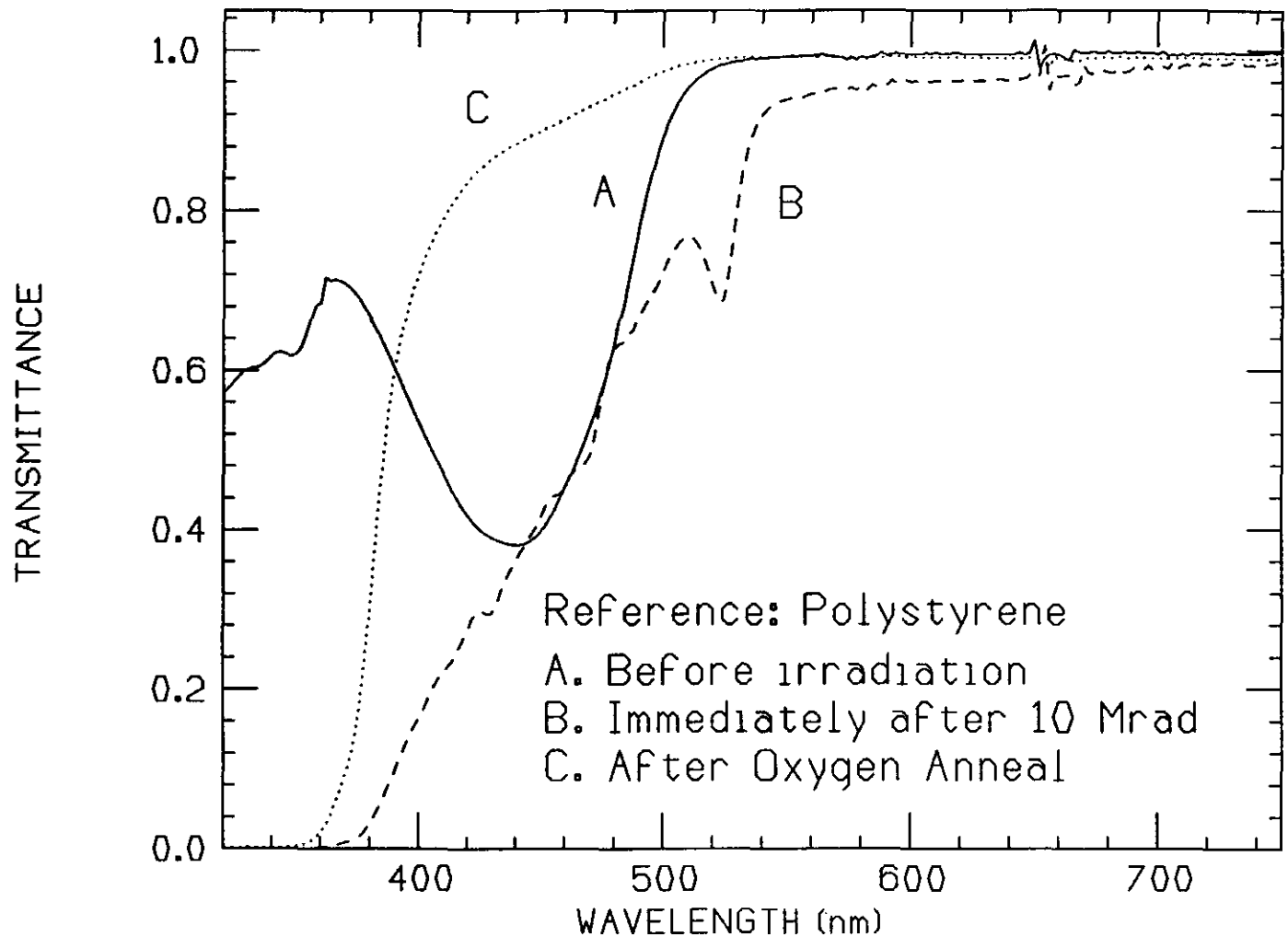


0.02% DIBRFN - HIGH DOSE RATE IRRADIATION IN AIR

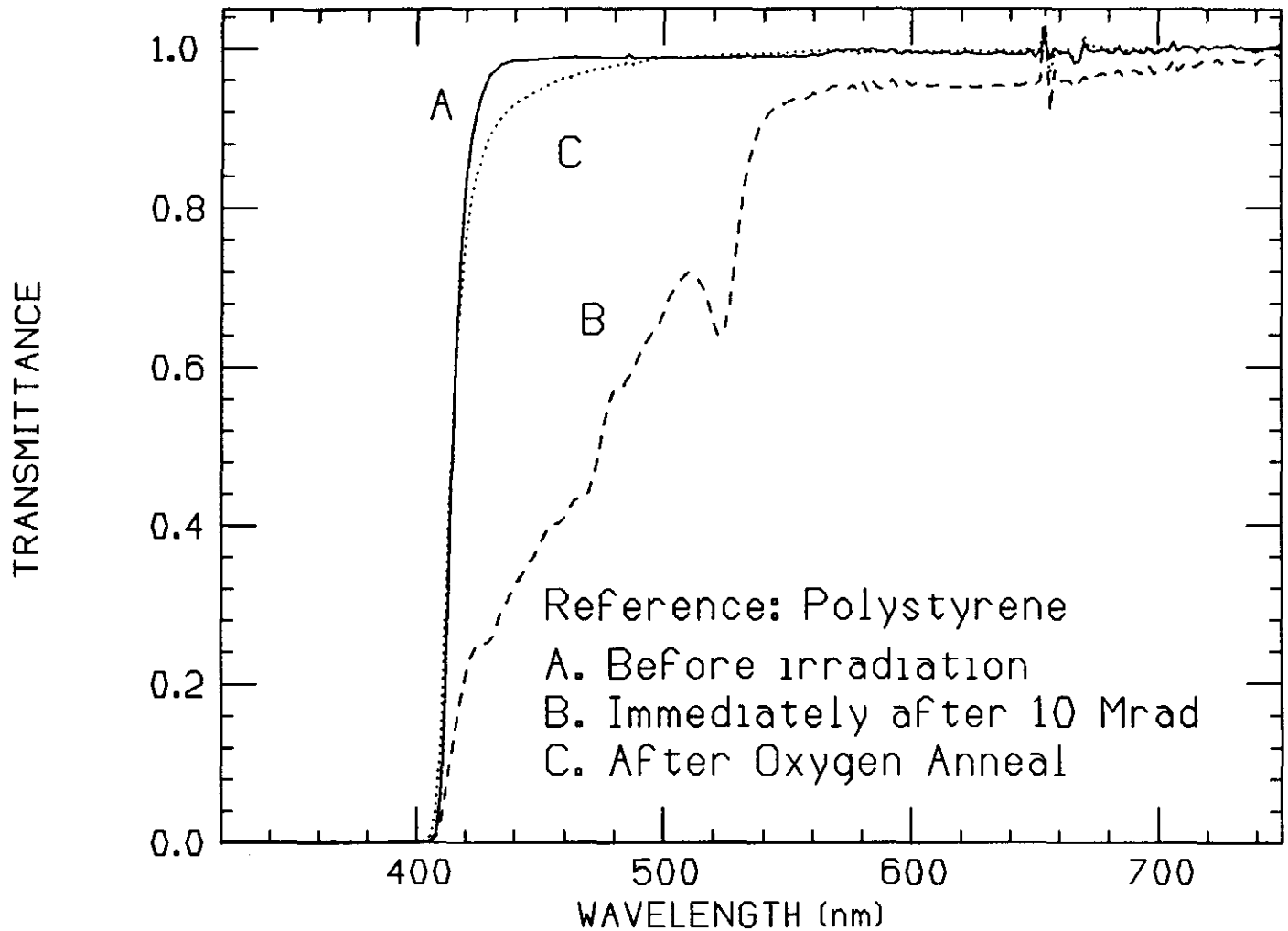



0.02% DICLFN/FN548-HIGH DOSE RATE IRRADIATION IN AIR
TRANSMITTANCE
1.0
0.8
0.6
0.4
0.2
0.0
400
500
600
700
WAVELENGTH (nm)
A
B
C
Reference: Polystyrene
A. Before irradiation
B. Immediately after 10 Mrad
C. After Oxygen Anneal

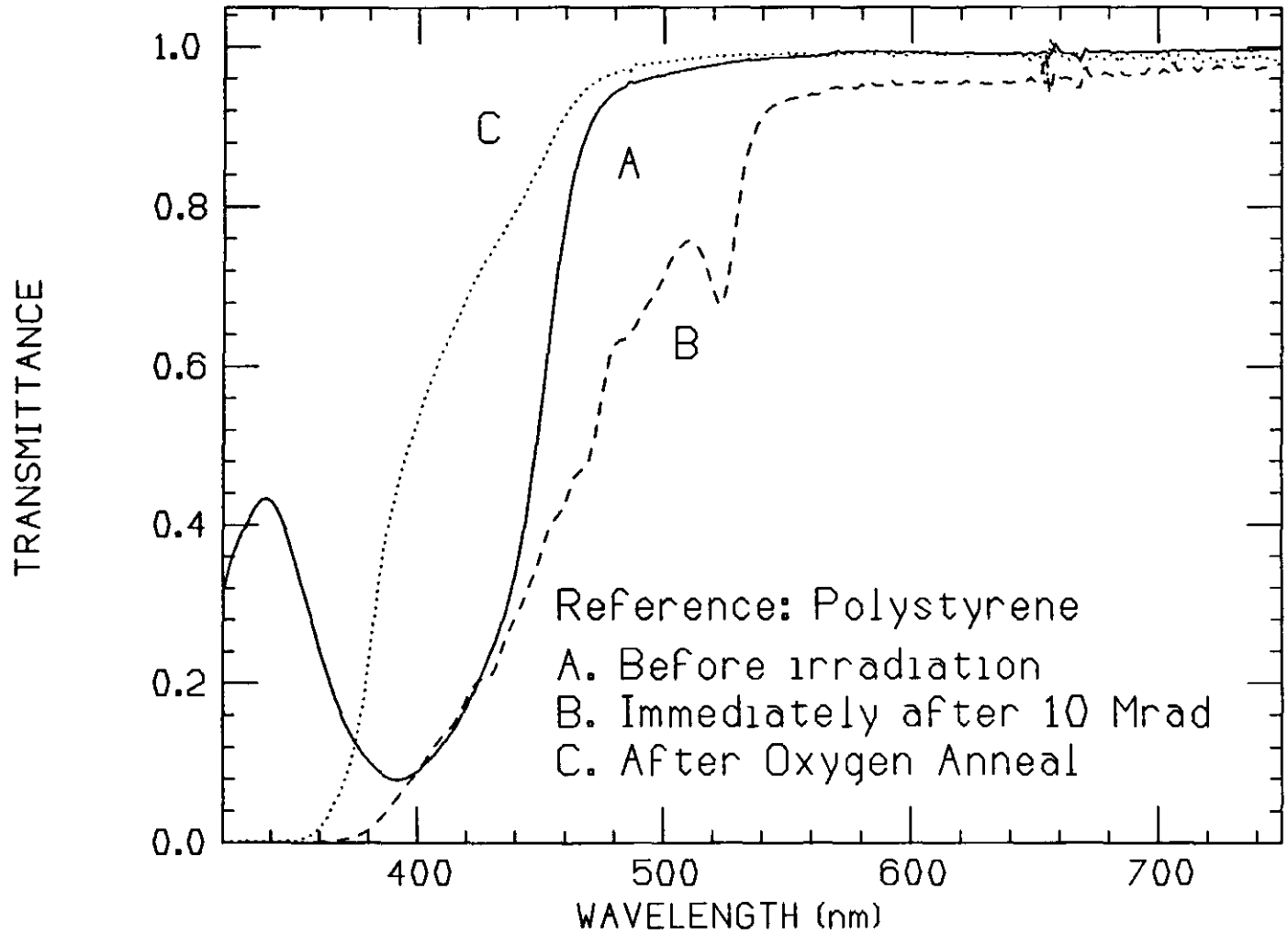
0.02% DMETCI - HIGH DOSE RATE IRRADIATION IN AIR



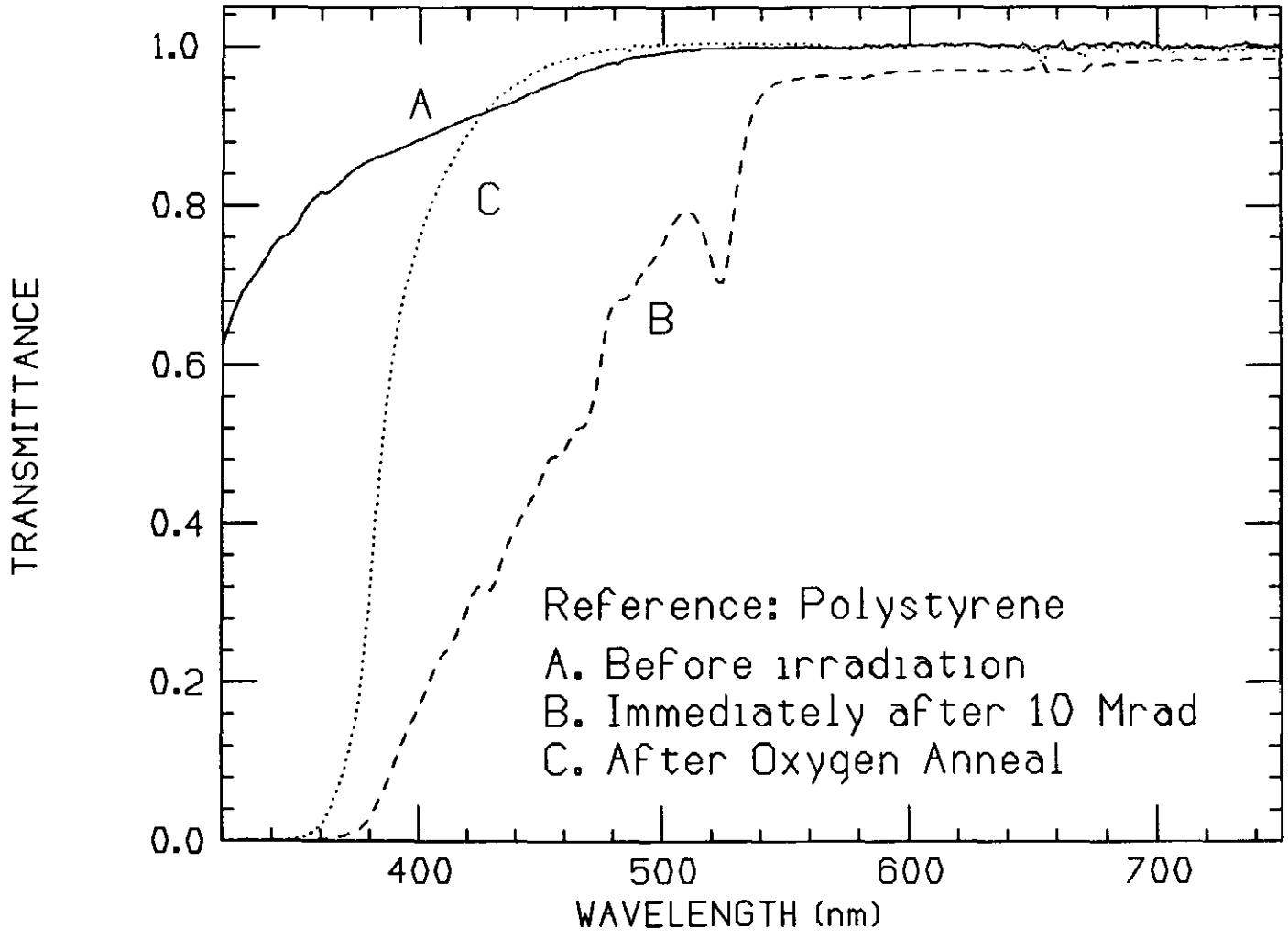
0.02% DMPOPOP - HIGH DOSE RATE IRRADIATION IN AIR



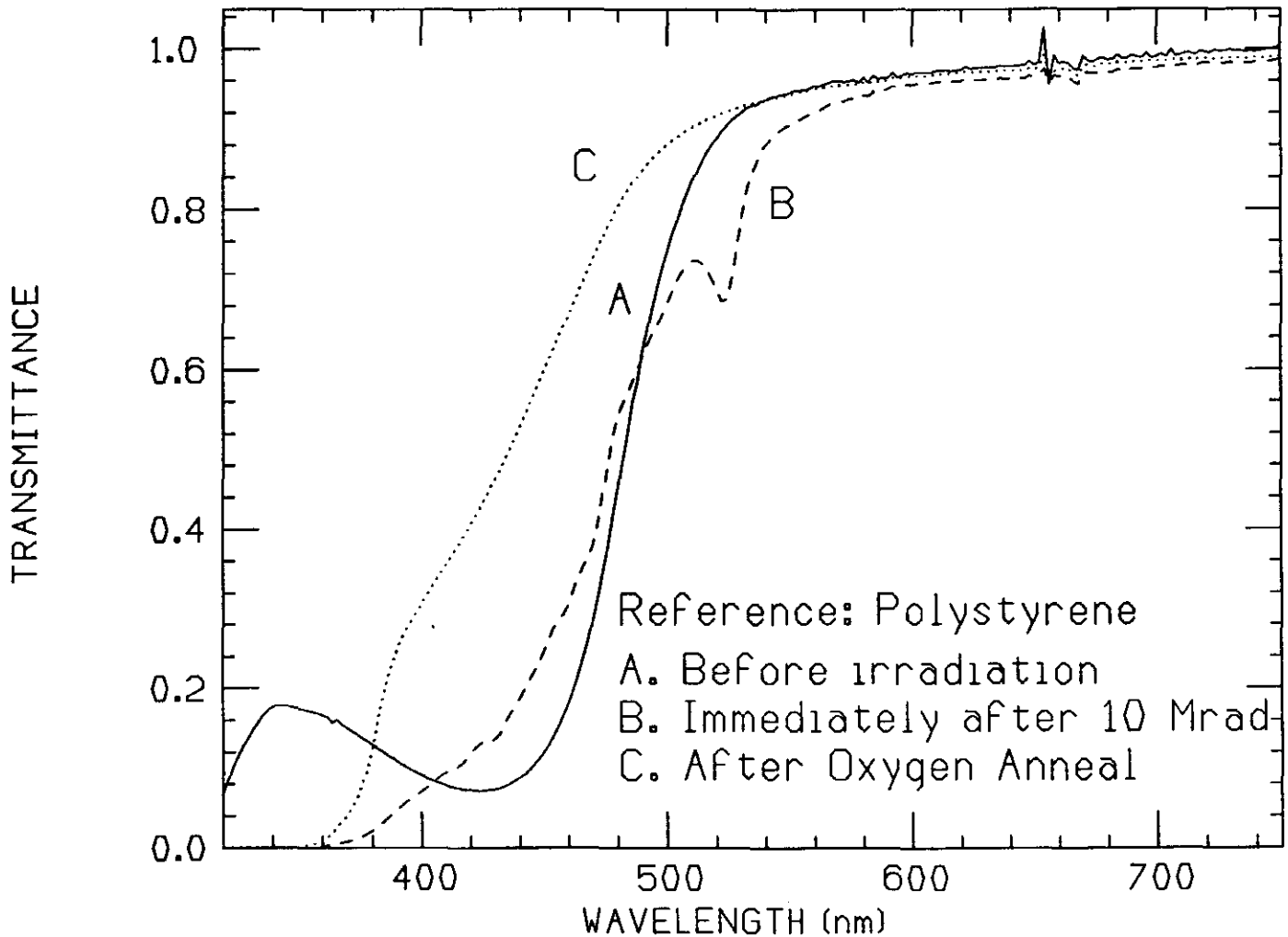
0.02% DOCI - HIGH DOSE RATE IRRADIATION IN AIR



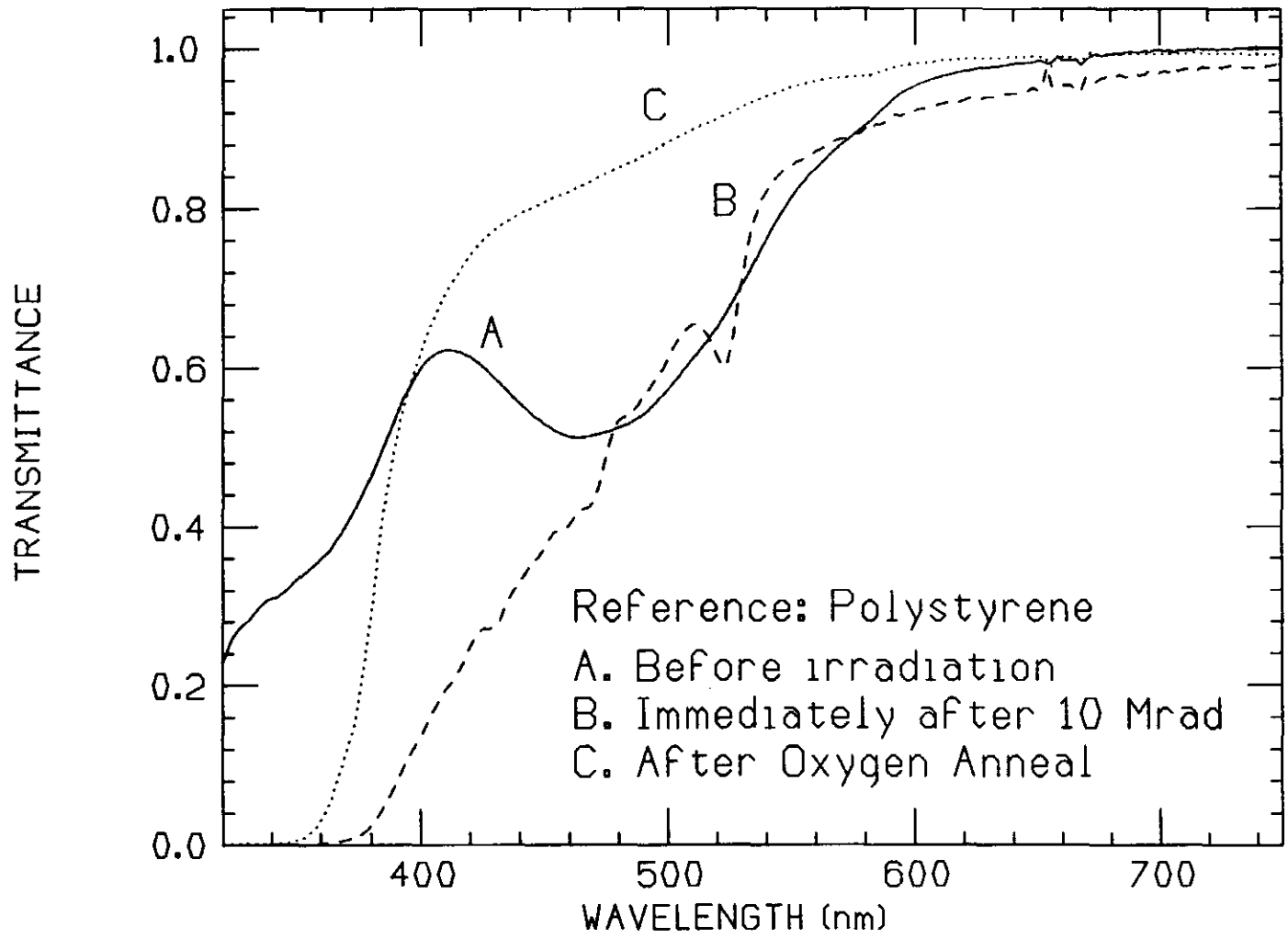
0.02% DODCI - HIGH DOSE RATE IRRADIATION IN AIR



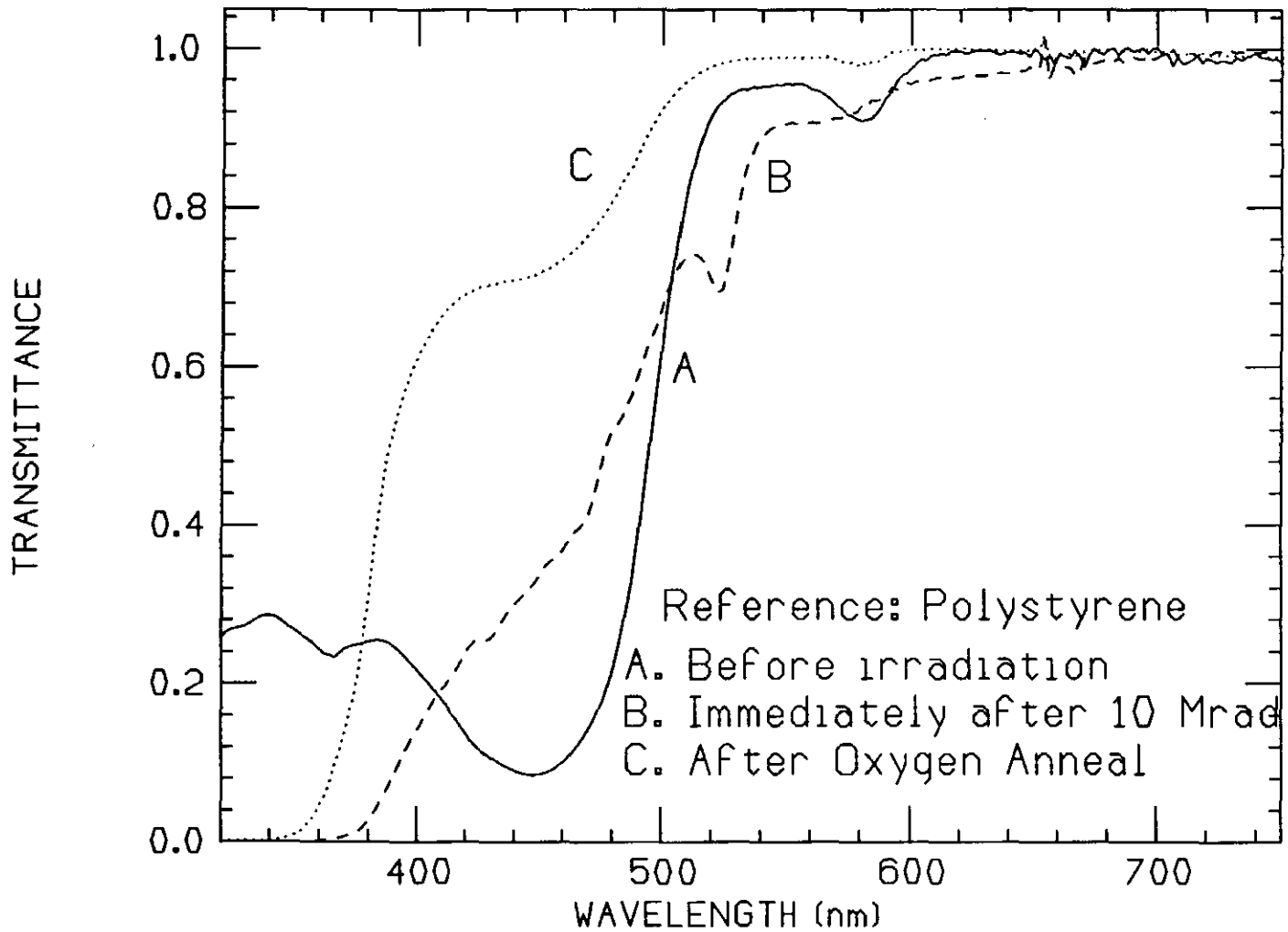
0.01% DODCI+C-E - HIGH DOSE RATE IRRADIATION IN AIR



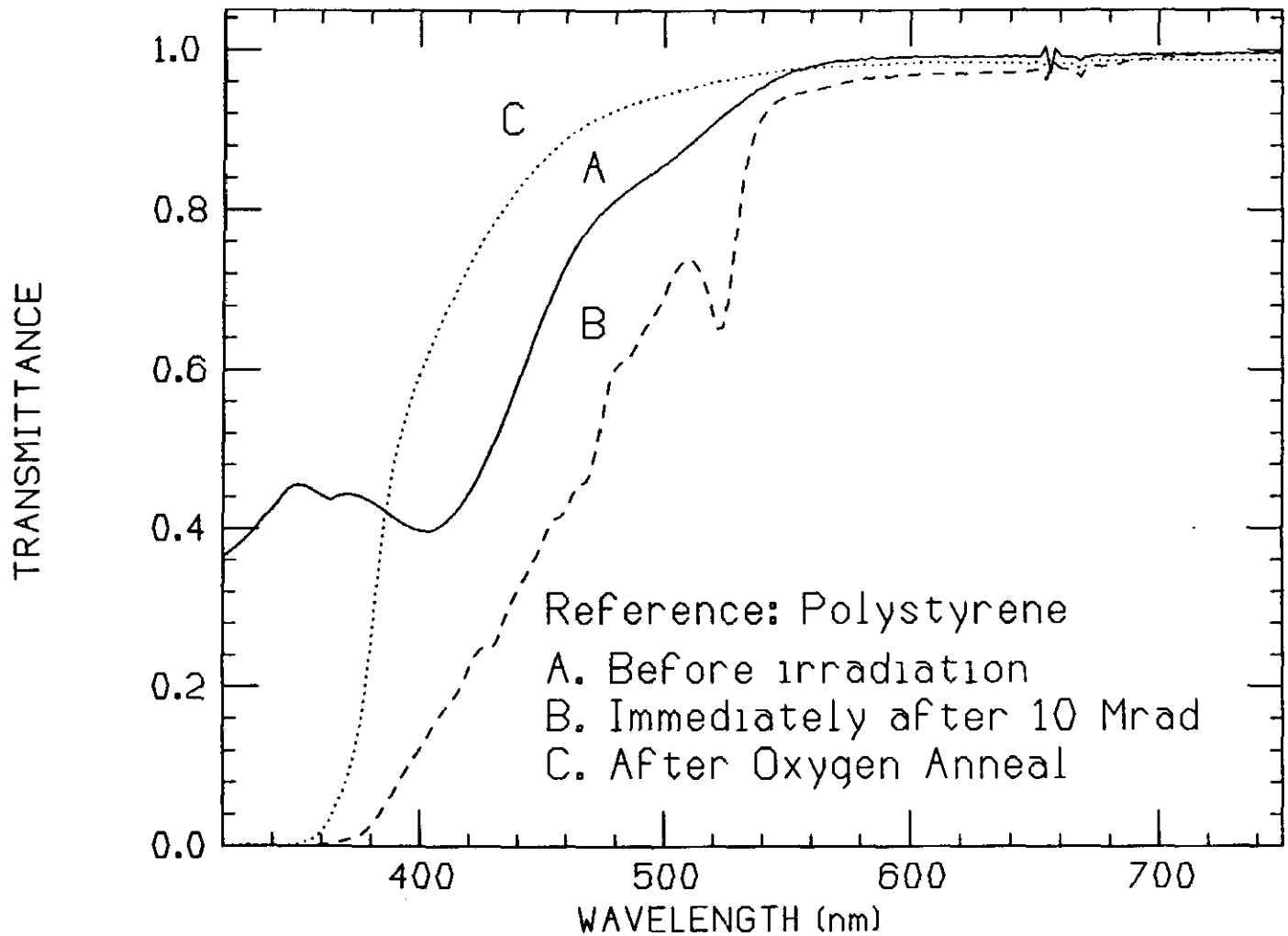
0.02% DQOCI - HIGH DOSE RATE IRRADIATION IN AIR



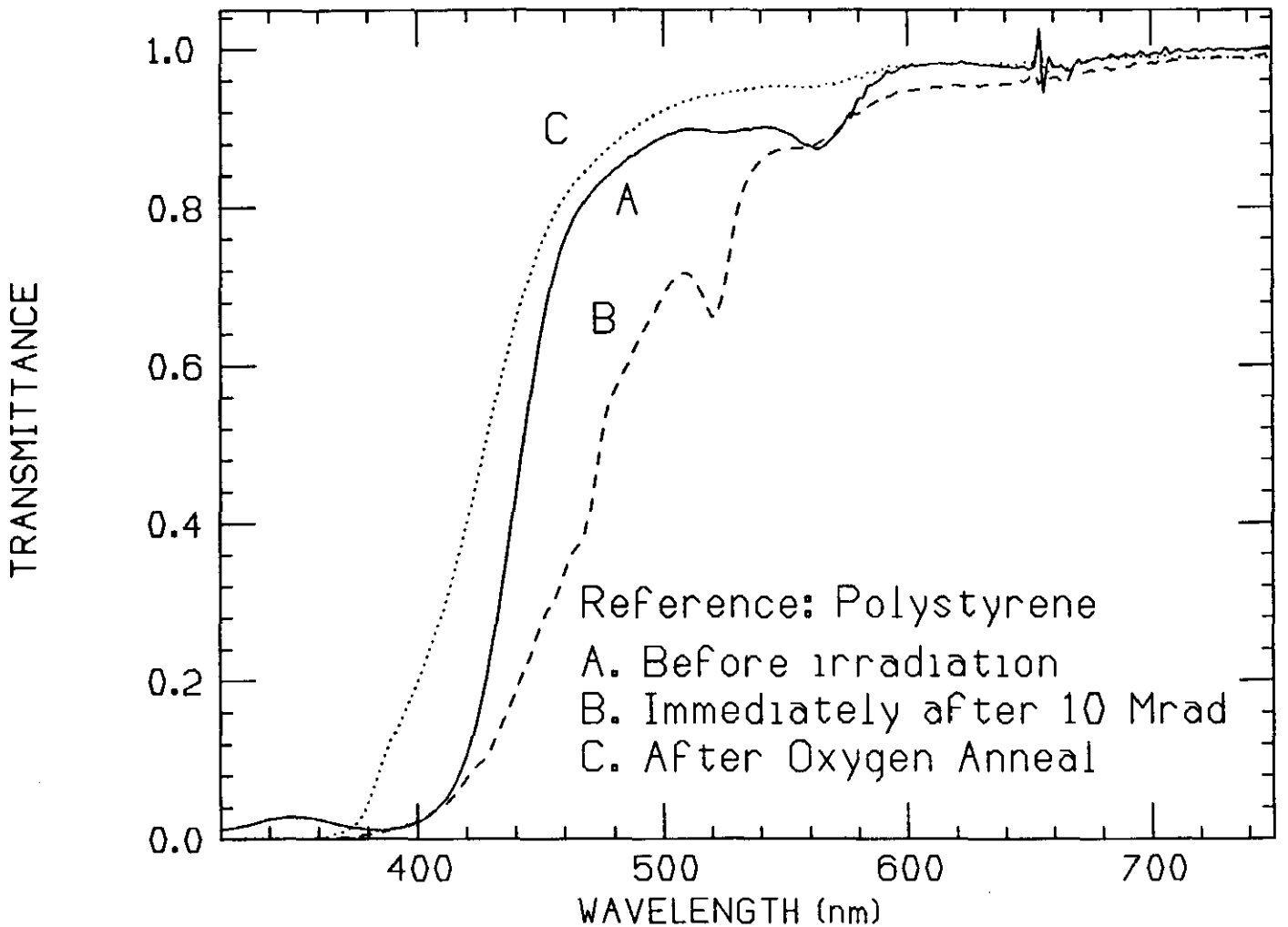
0.02% DTCI - HIGH DOSE RATE IRRADIATION IN AIR



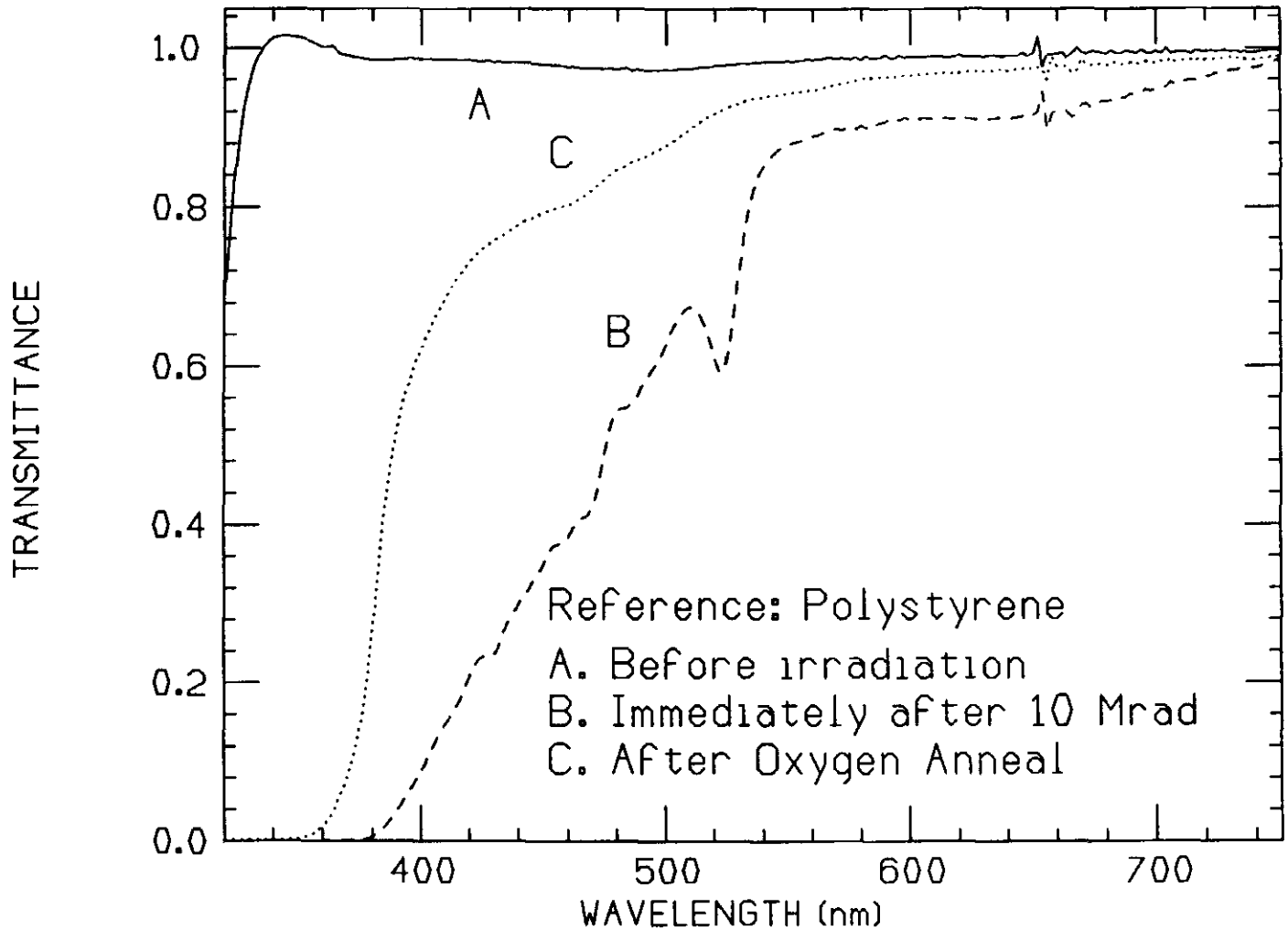
0.01% DTDCI - HIGH DOSE RATE IRRADIATION IN AIR



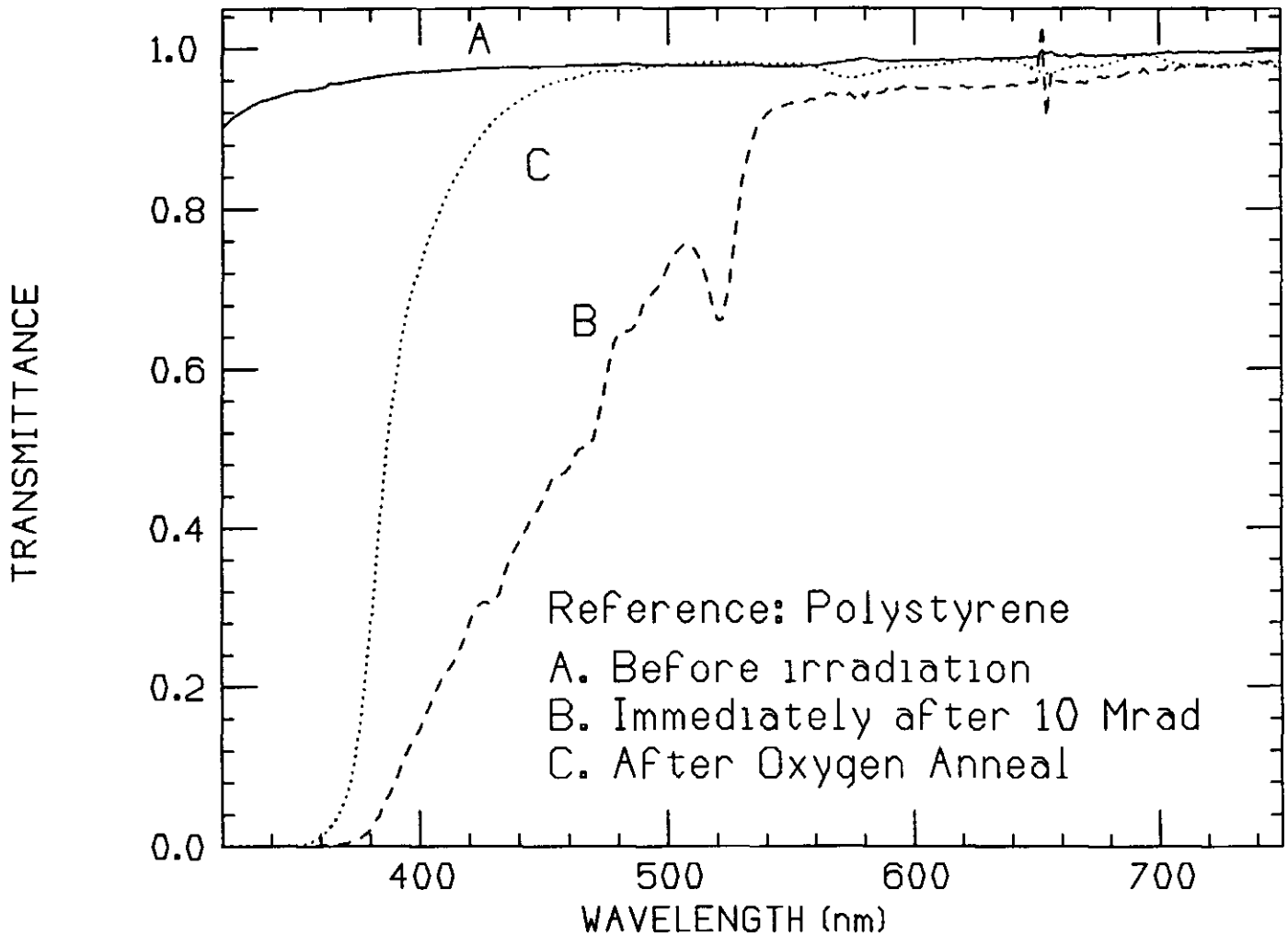
0.01% HIDCI+C-E - HIGH DOSE RATE IRRADIATION IN AIR



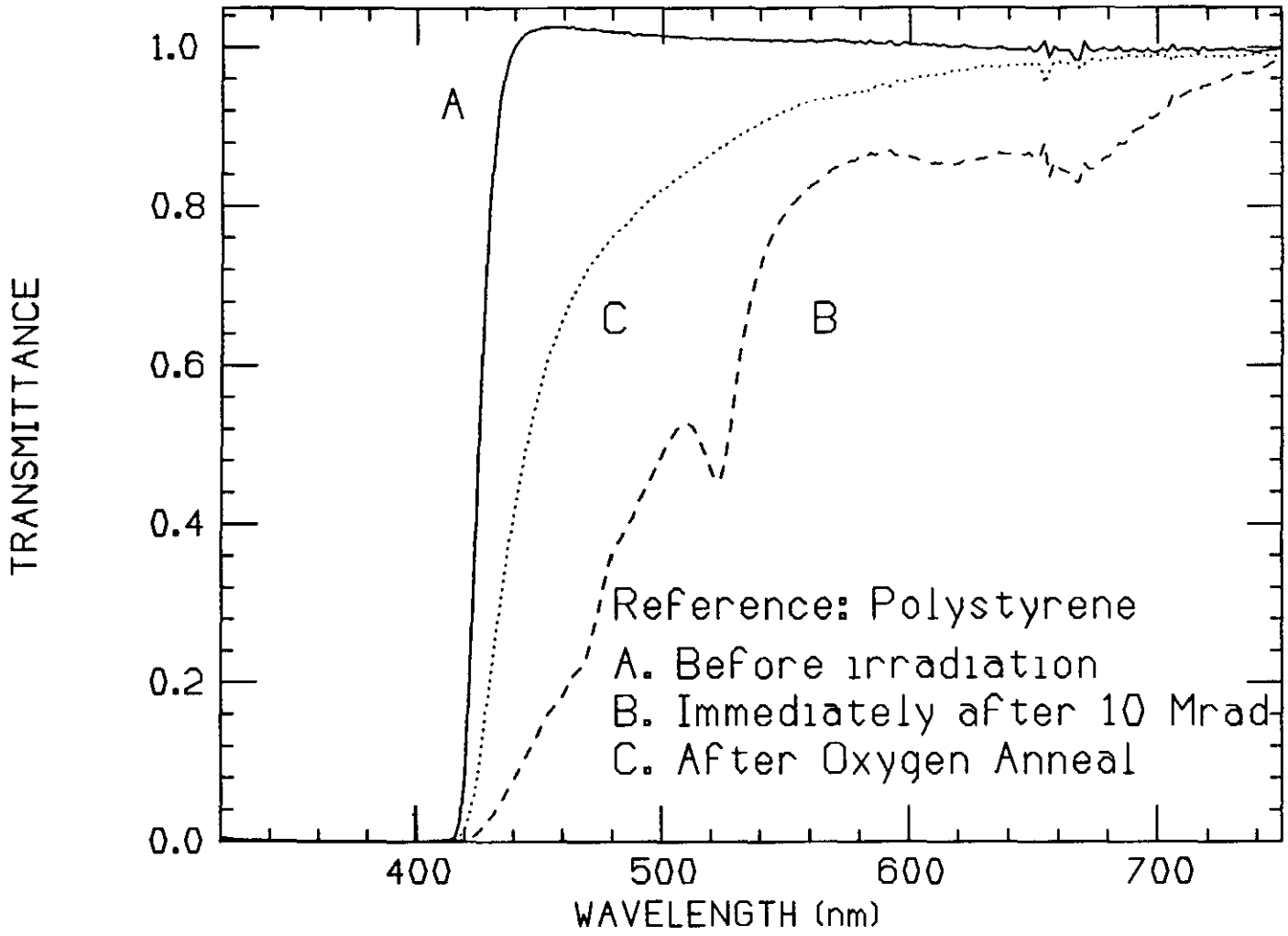
0.02% ISCNFN - HIGH DOSE RATE IRRADIATION IN AIR



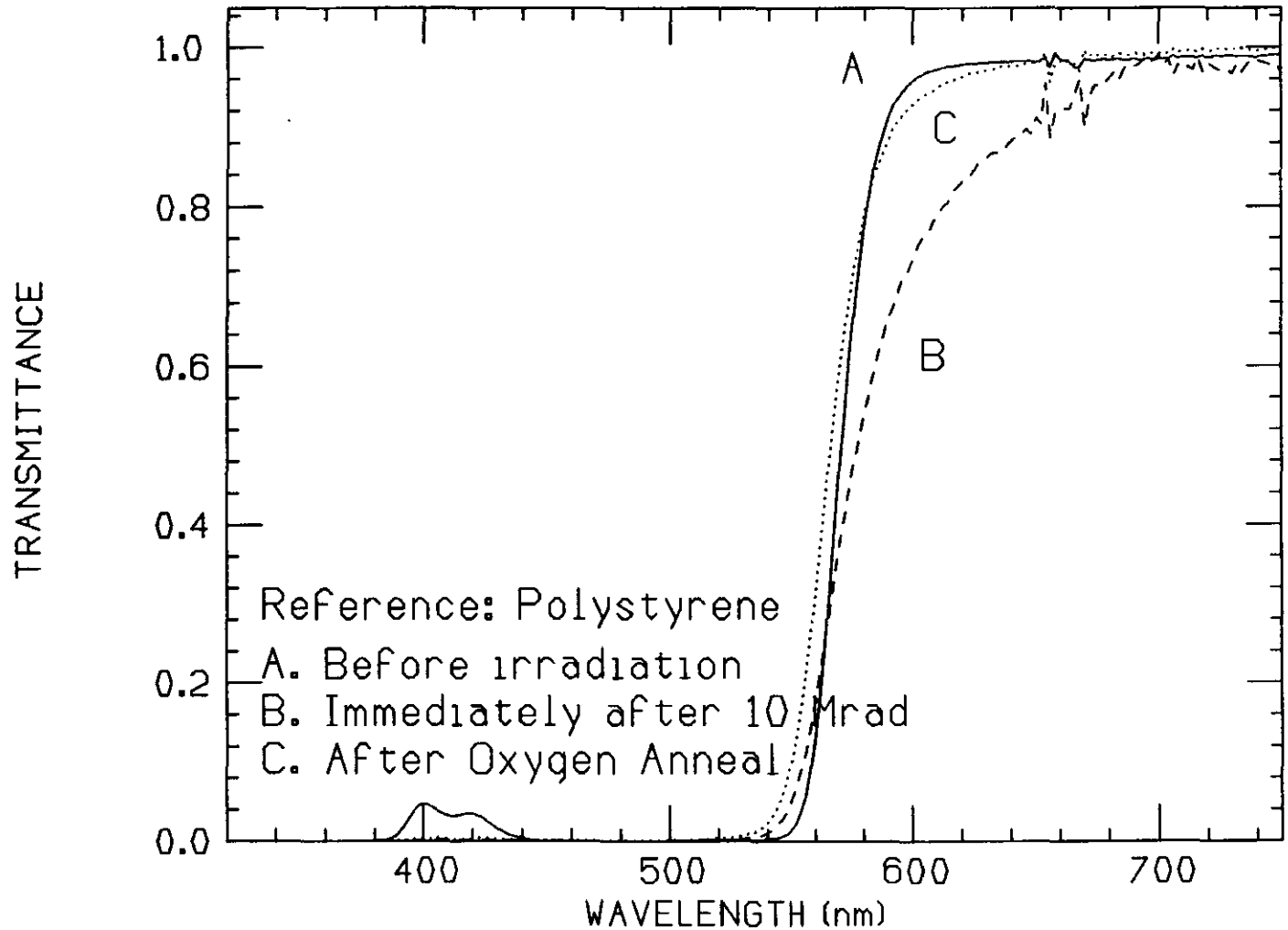
0.02% KITON RED - HIGH DOSE RATE IRRADIATION IN AIR

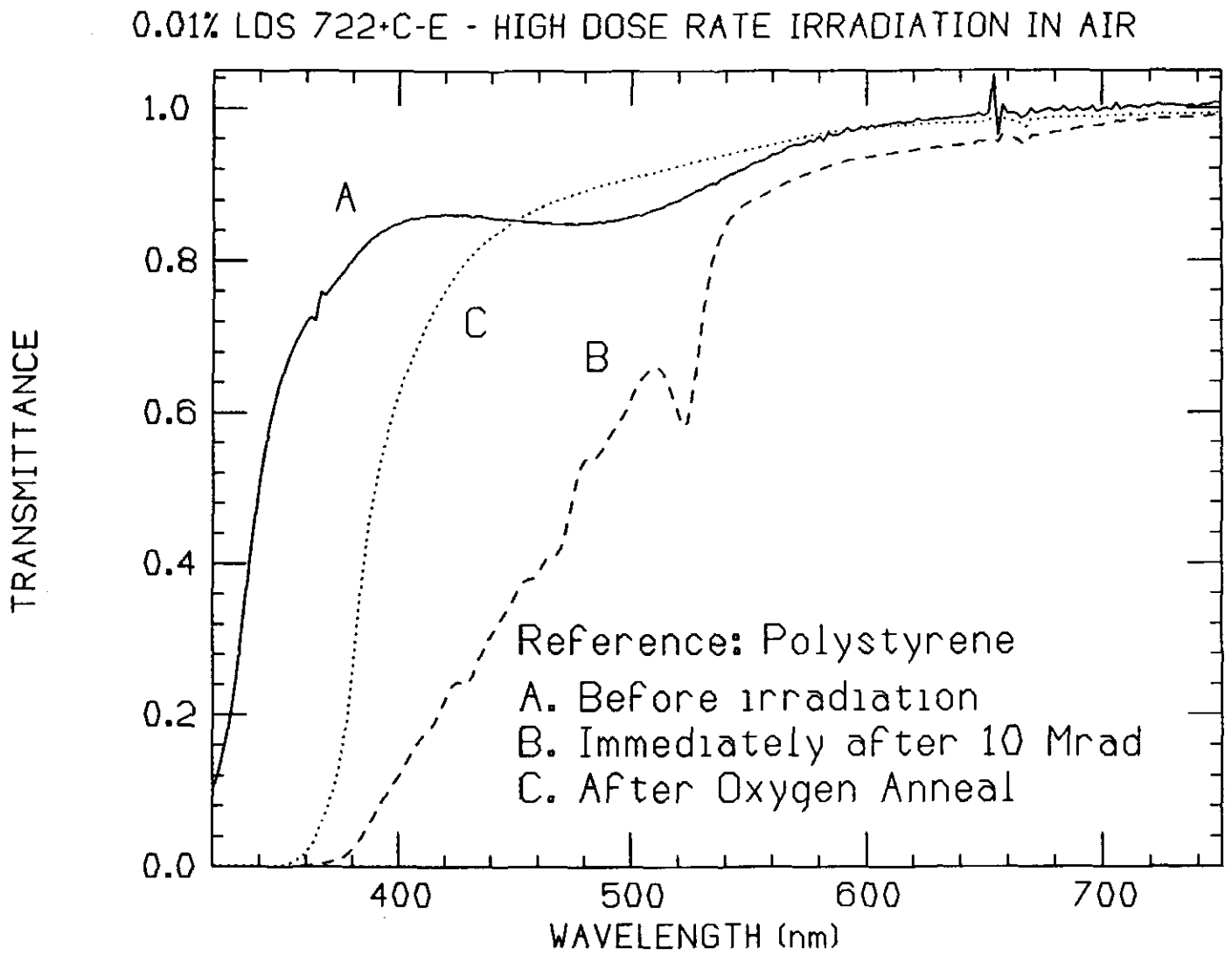


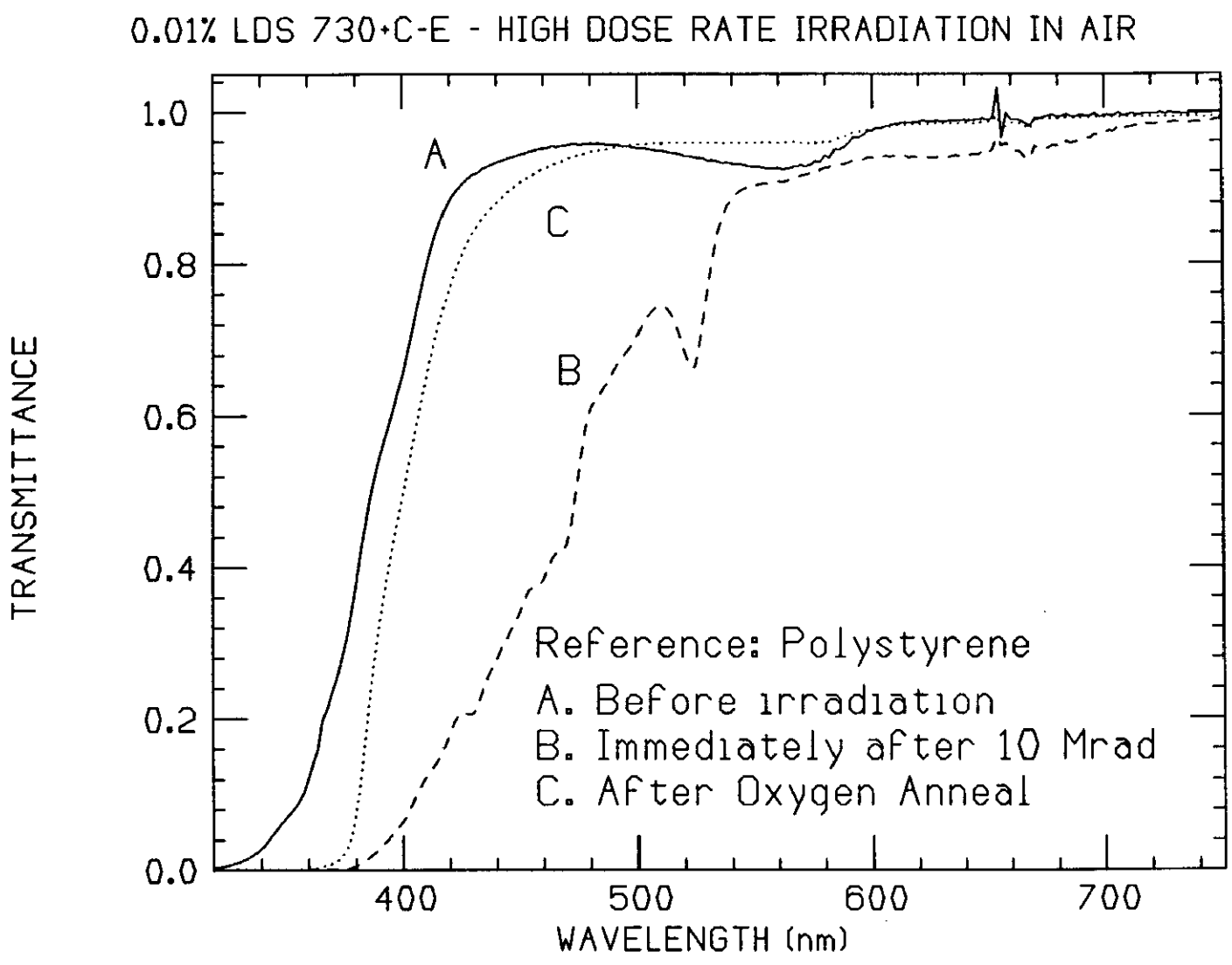
0.02% LD 490 - HIGH DOSE RATE IRRADIATION IN AIR

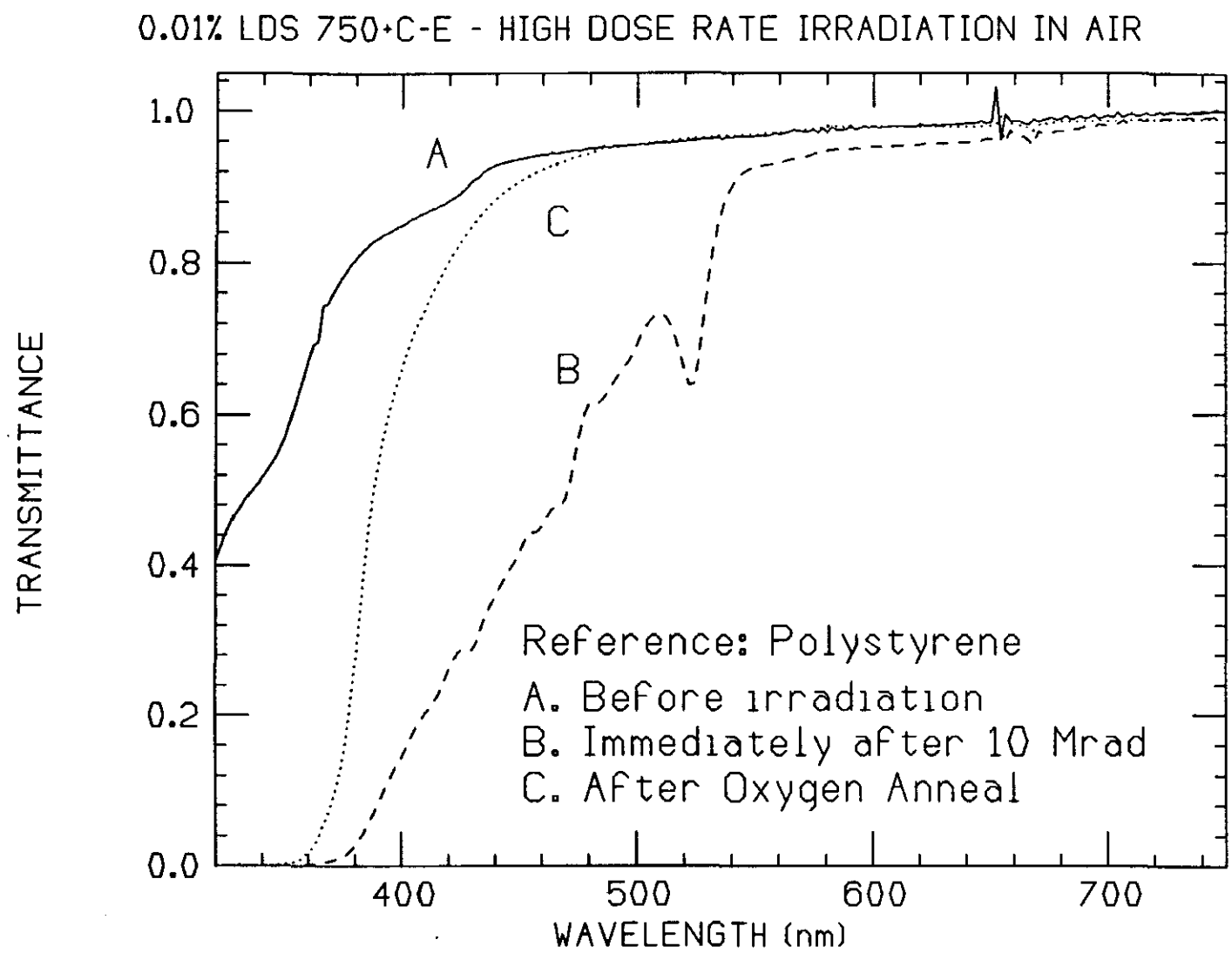


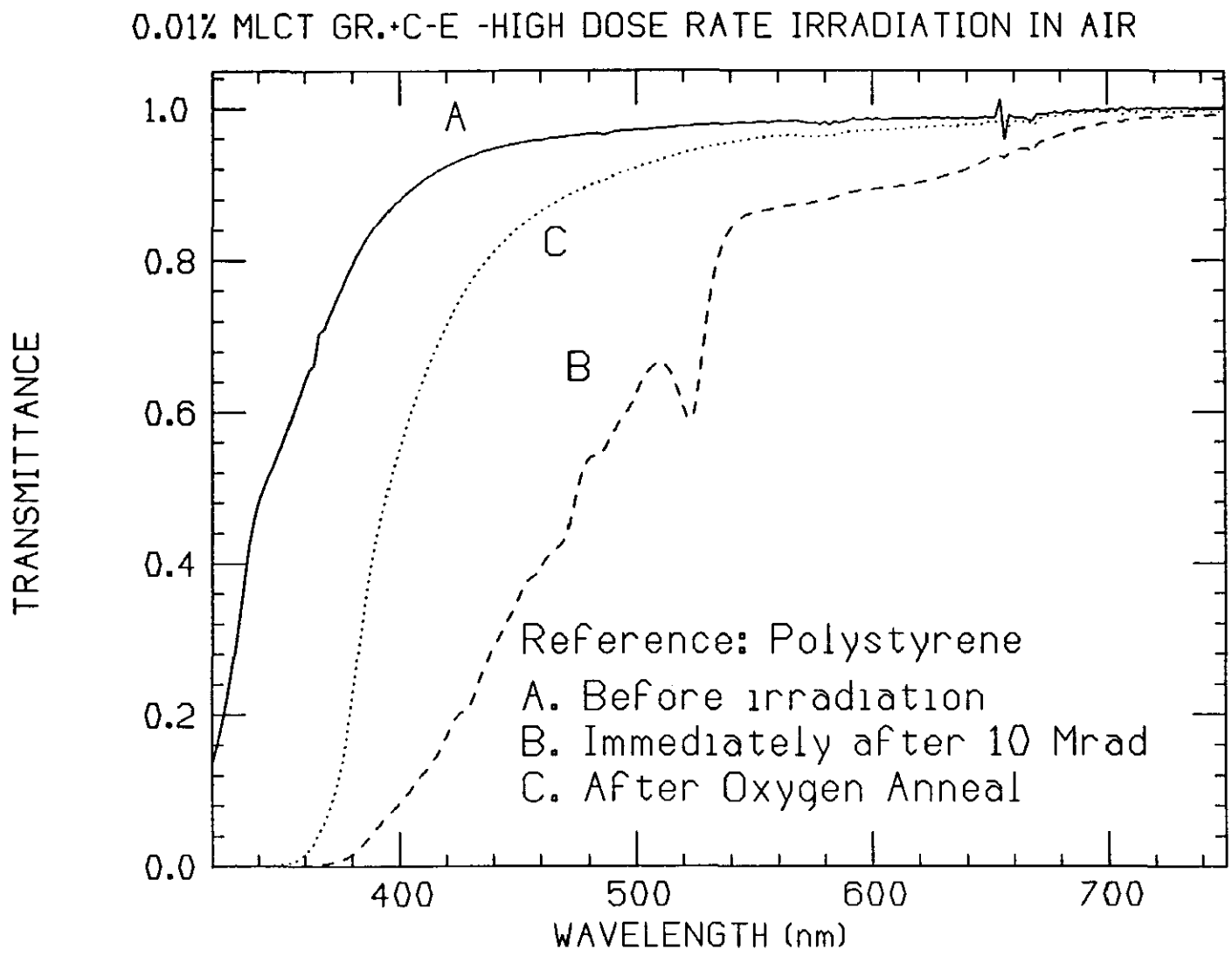
0.02% LD 688 - HIGH DOSE RATE IRRADIATION IN AIR



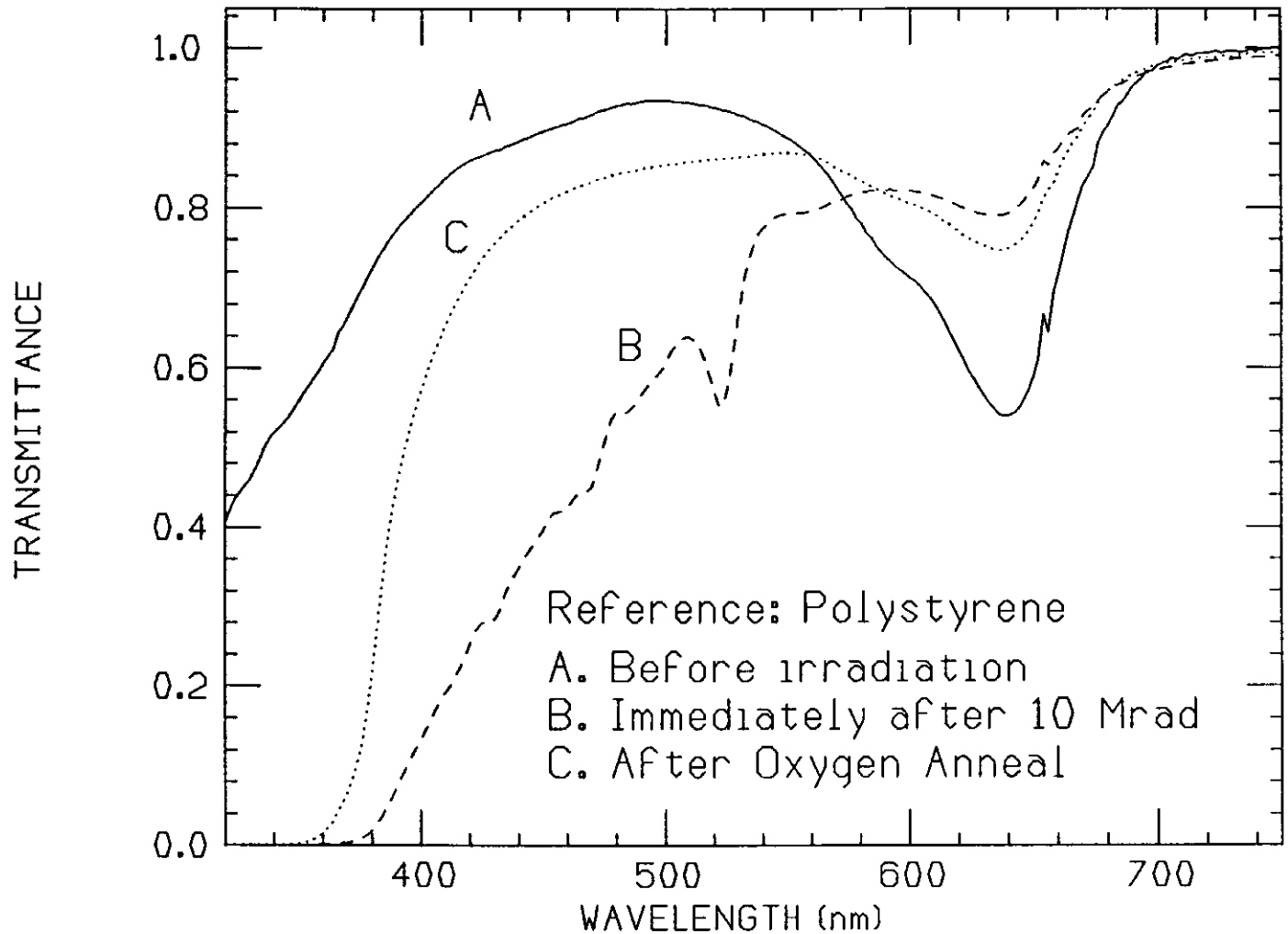

0.01% LDS 722+C-E - HIGH DOSE RATE IRRADIATION IN AIR
TRANSMITTANCE
1.0
0.8
0.6
0.4
0.2
0.0
400
500
600
700
WAVELENGTH (nm)
A
B
C
Reference: Polystyrene
A. Before irradiation
B. Immediately after 10 Mrad
C. After Oxygen Anneal

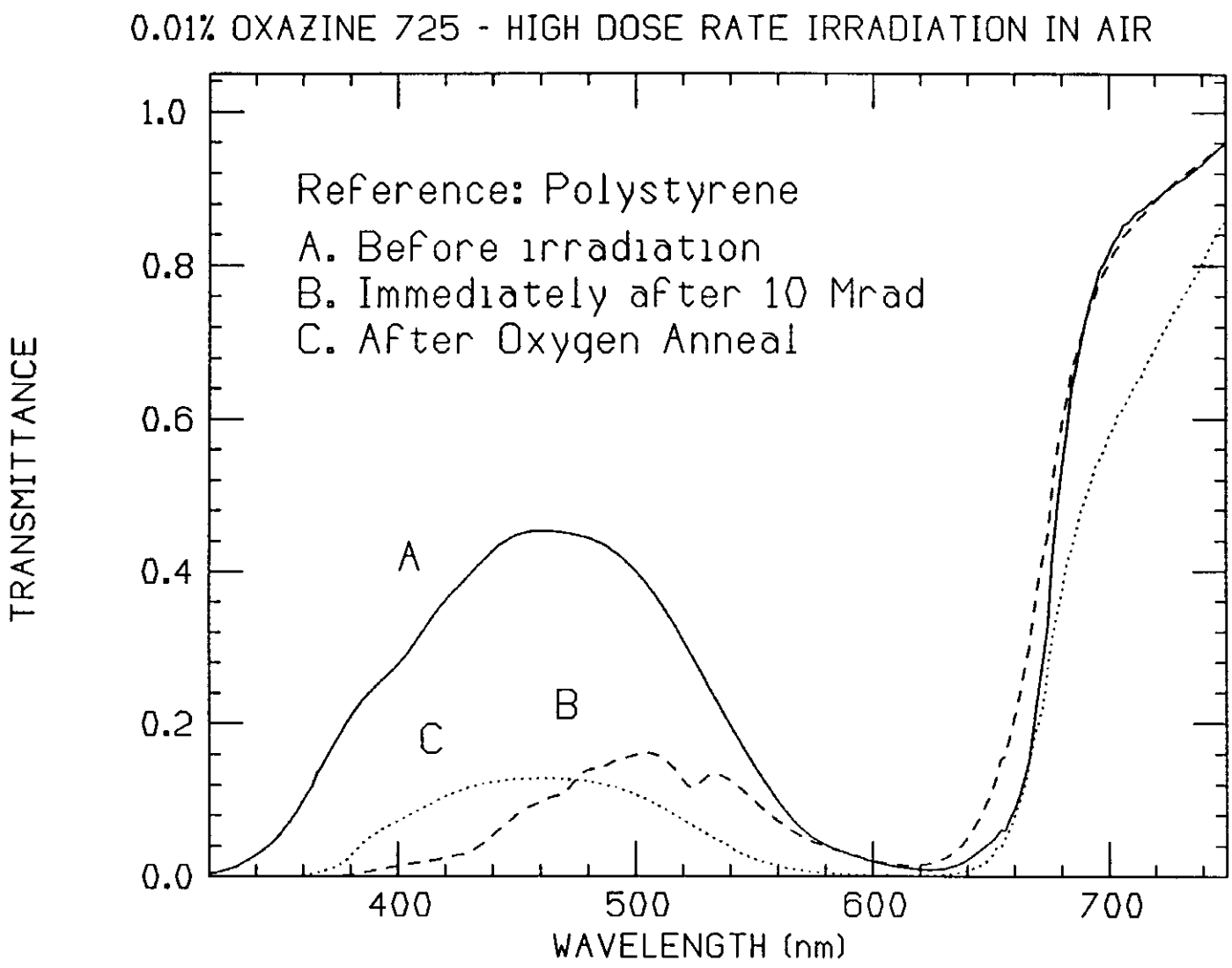

0.01% LDS 730+C-E - HIGH DOSE RATE IRRADIATION IN AIR
TRANSMITTANCE
1.0
0.8
0.6
0.4
0.2
0.0
400
500
600
700
WAVELENGTH (nm)
A
B
C
Reference: Polystyrene
A. Before irradiation
B. Immediately after 10 Mrad
C. After Oxygen Anneal


0.01% LDS 750+C-E - HIGH DOSE RATE IRRADIATION IN AIR
TRANSMITTANCE
1.0
0.8
0.6
0.4
0.2
0.0
400
500
600
700
WAVELENGTH (nm)
A
B
C
Reference: Polystyrene
A. Before irradiation
B. Immediately after 10 Mrad
C. After Oxygen Anneal

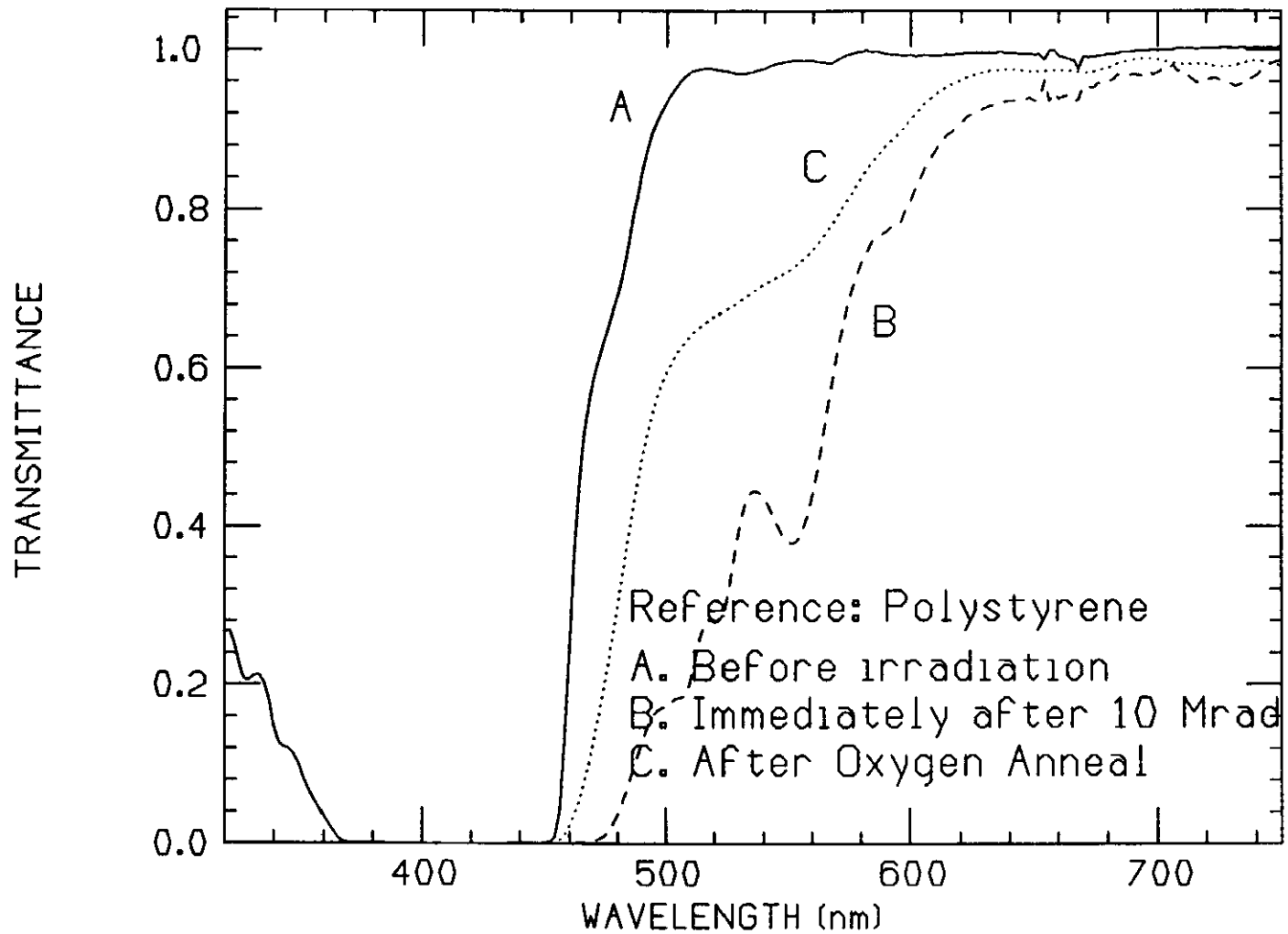

0.01% MLCT GR.+C-E -HIGH DOSE RATE IRRADIATION IN AIR
TRANSMITTANCE
1.0
0.8
0.6
0.4
0.2
0.0
400
500
600
700
WAVELENGTH (nm)
A
B
C
Reference: Polystyrene
A. Before irradiation
B. Immediately after 10 Mrad
C. After Oxygen Anneal

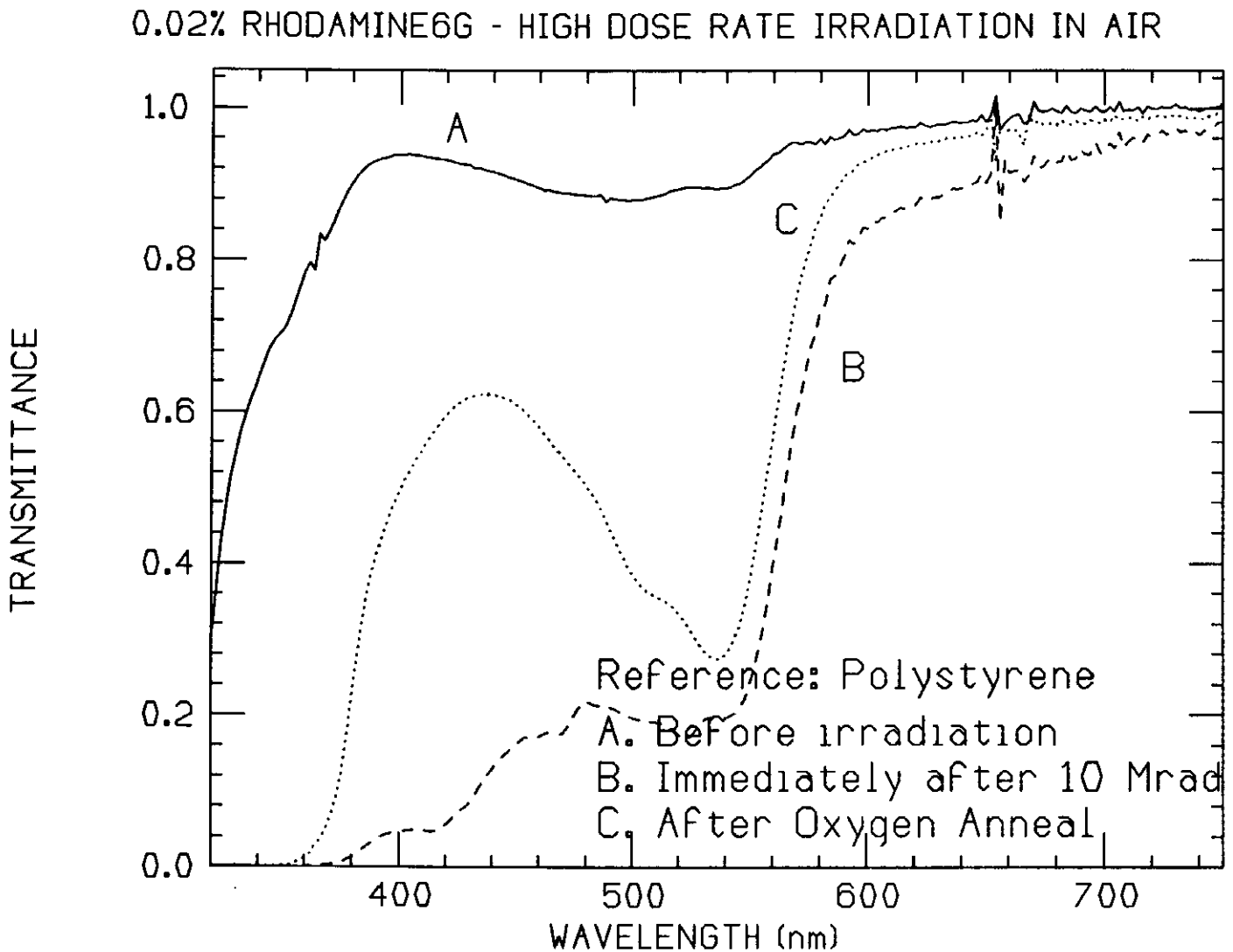
0.01% NLE B.690+C-E-HIGH DOSE RATE IRRADIATION IN AIR

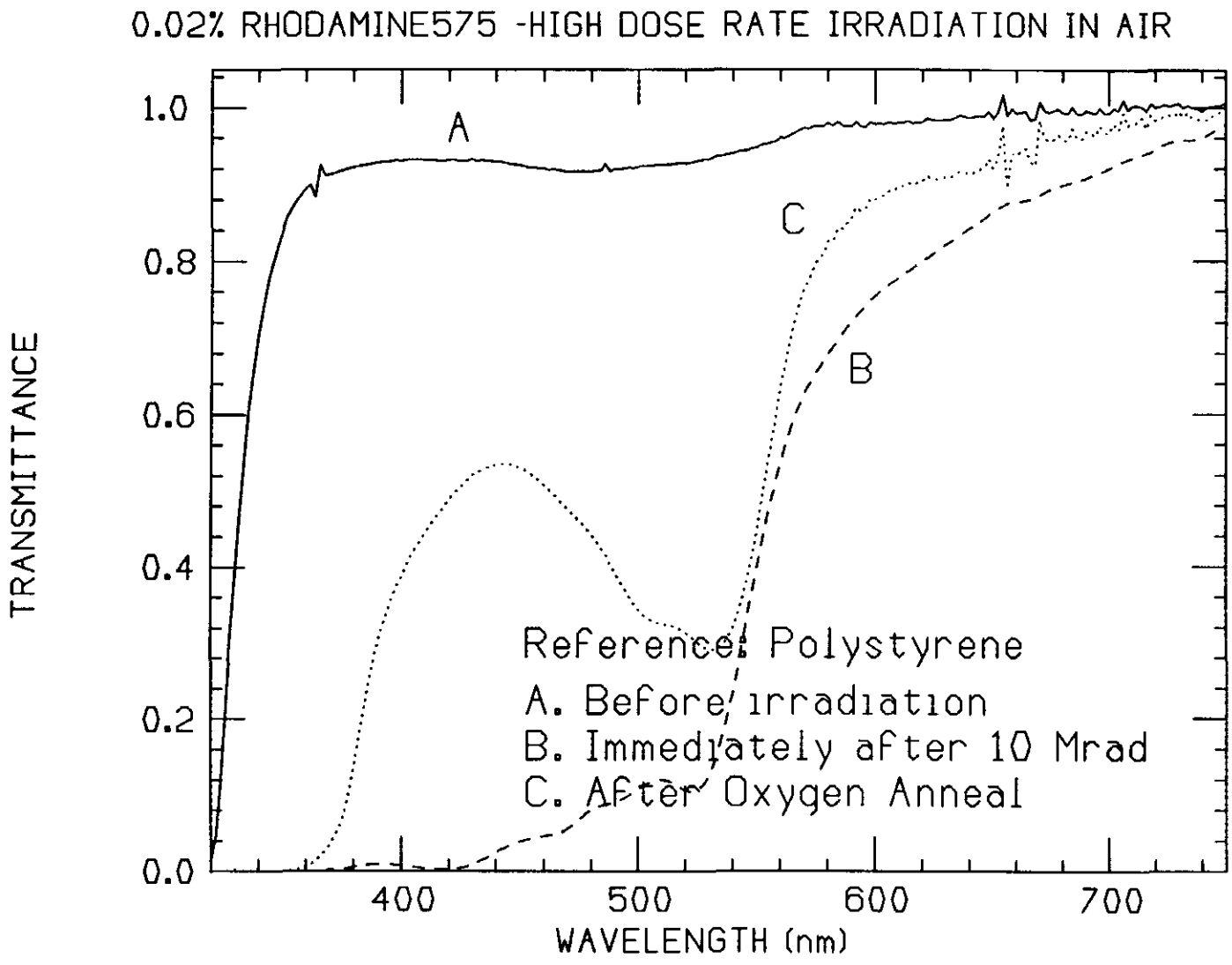


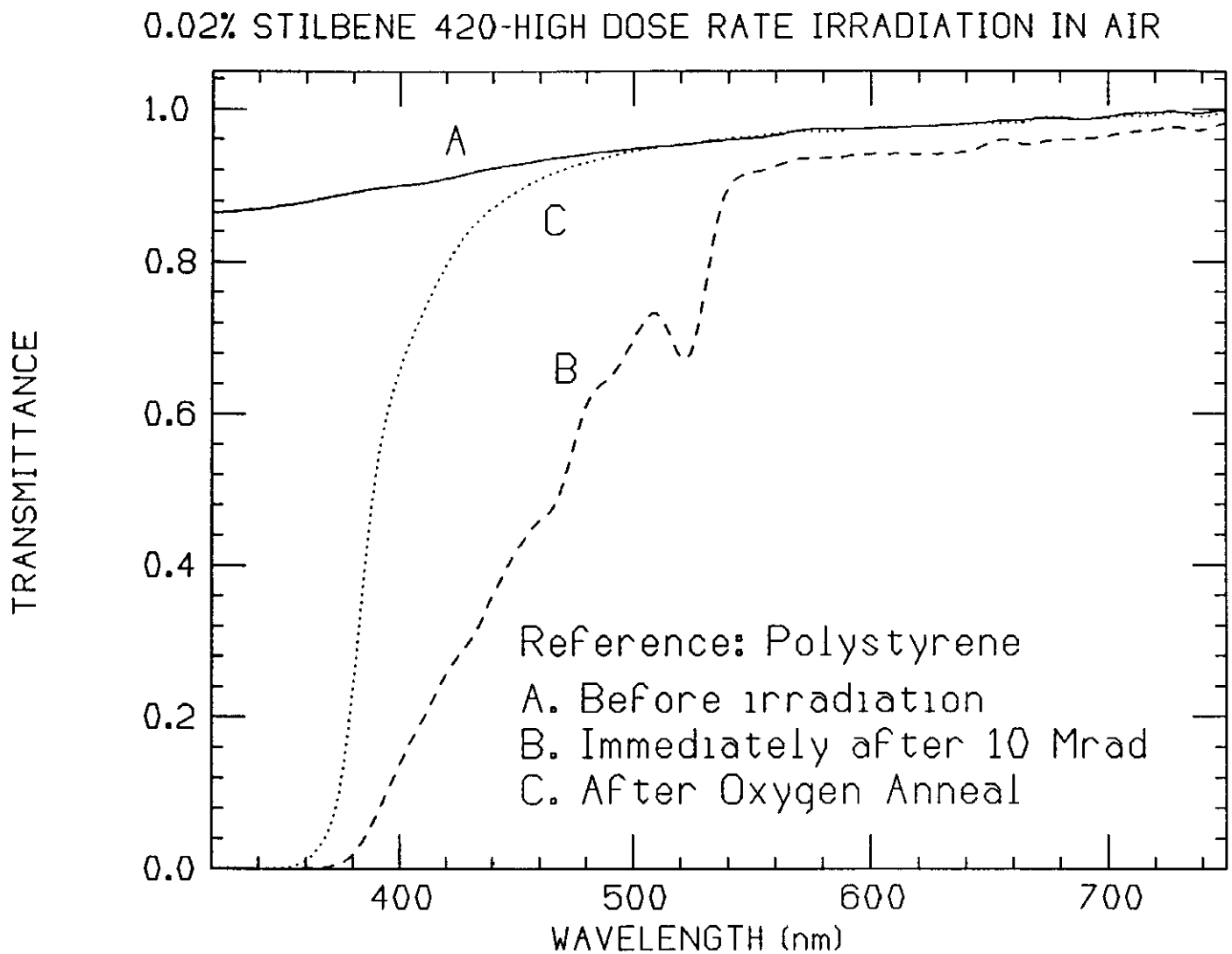

0.01% OXAZINE 725 - HIGH DOSE RATE IRRADIATION IN AIR
Reference: Polystyrene
A. Before irradiation
B. Immediately after 10 Mrad
C. After Oxygen Anneal
A
B
C
TRANSMITTANCE
1.0
0.8
0.6
0.4
0.2
0.0
400
500
600
700
WAVELENGTH (nm)

0.02% PYRIDINE1 - HIGH DOSE RATE IRRADIATION IN AIR

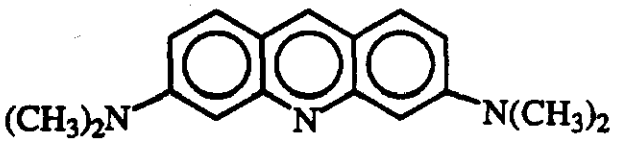



0.02% RHODAMINE6G - HIGH DOSE RATE IRRADIATION IN AIR
TRANSMITTANCE
1.0
0.8
0.6
0.4
0.2
0.0
400
500
600
700
WAVELENGTH (nm)
A
B
C
Reference: Polystyrene
A. Before irradiation
B. Immediately after 10 Mrad
C. After Oxygen Anneal

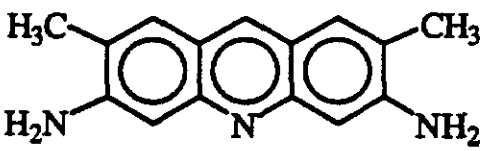

0.02% RHODAMINE575 -HIGH DOSE RATE IRRADIATION IN AIR
TRANSMITTANCE
1.0
0.8
0.6
0.4
0.2
0.0
400
500
600
700
WAVELENGTH (nm)
A
B
C
Reference: Polystyrene
A. Before irradiation
B. Immediately after 10 Mrad
C. After Oxygen Anneal


0.02% STILBENE 420-HIGH DOSE RATE IRRADIATION IN AIR
TRANSMITTANCE
1.0
0.8
0.6
0.4
0.2
0.0
400
500
600
700
WAVELENGTH (nm)
A
B
C
Reference: Polystyrene
A. Before irradiation
B. Immediately after 10 Mrad
C. After Oxygen Anneal

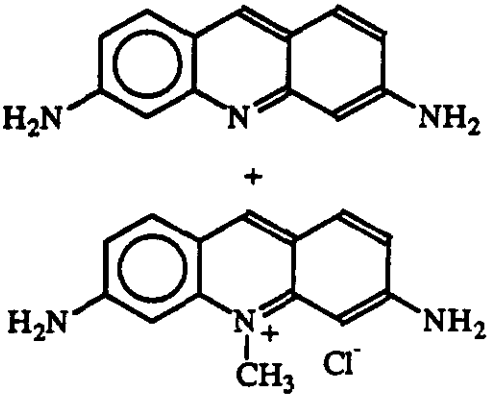
APPENDIX A: LIST OF DOPANT STRUCTURES



ACRIDINE O B



· HCl



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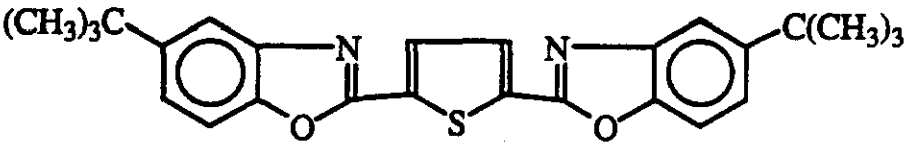
ACRIFLAVINE



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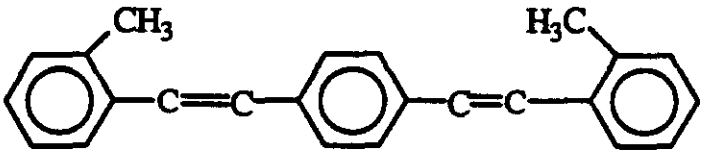

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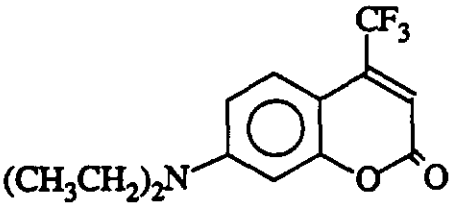

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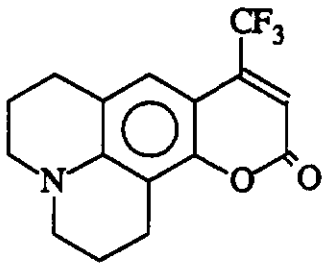

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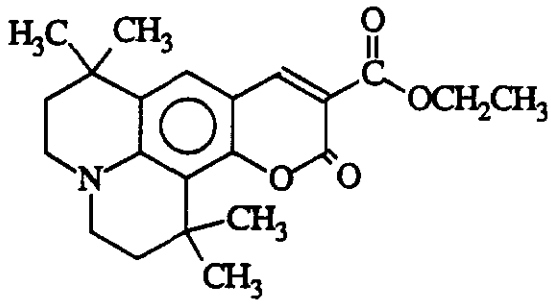

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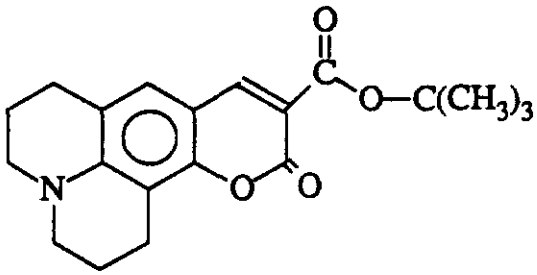

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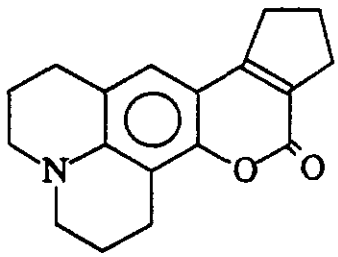

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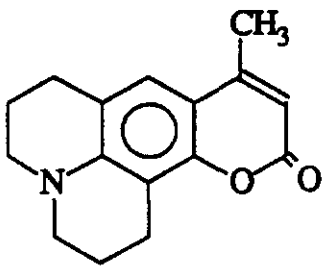

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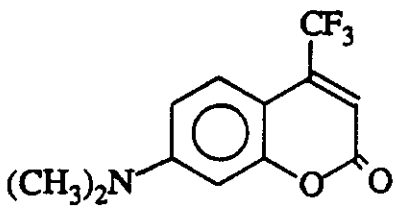

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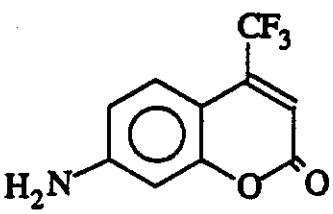

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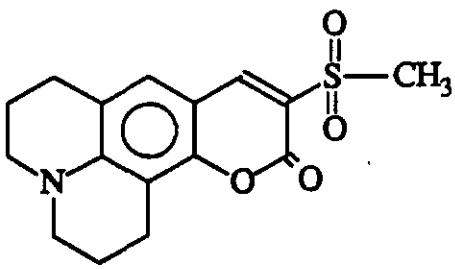

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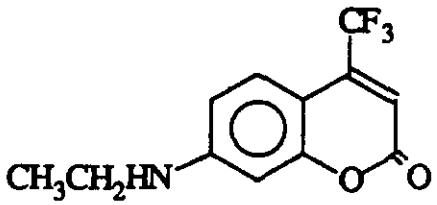

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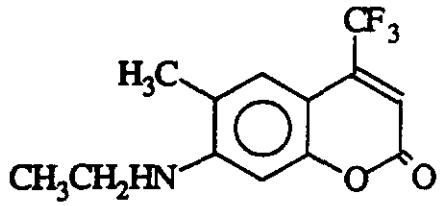

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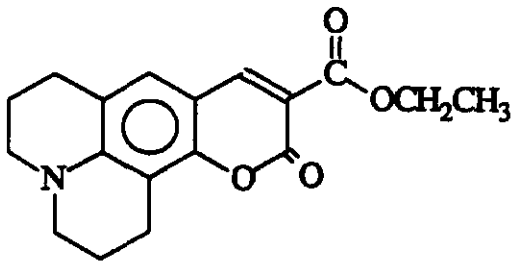

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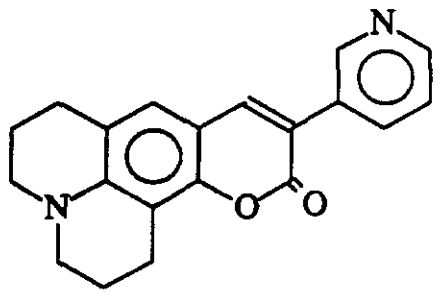

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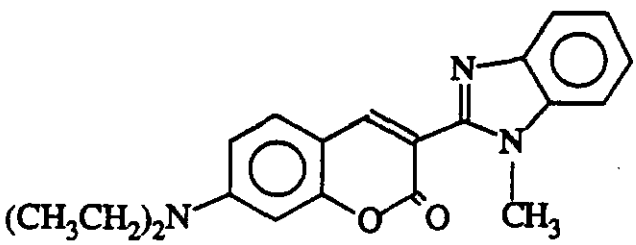

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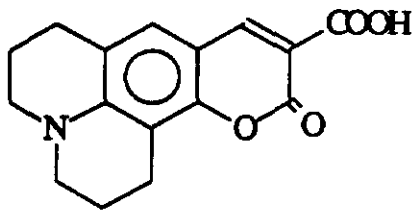

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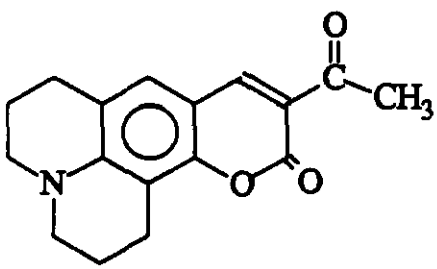

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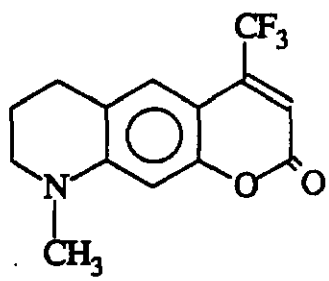

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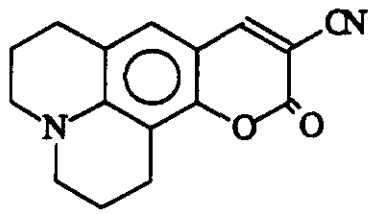

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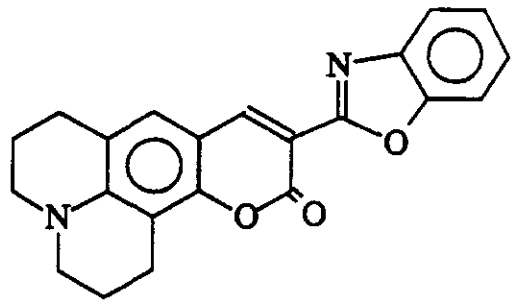

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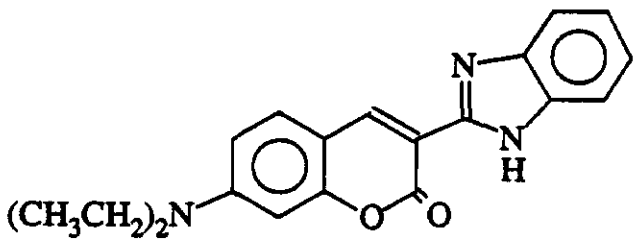

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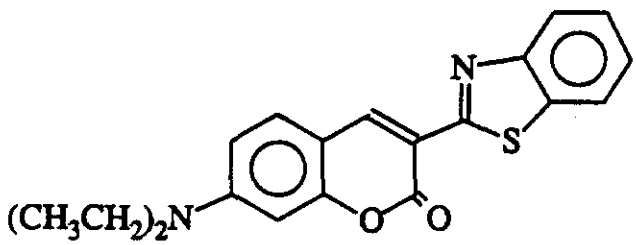

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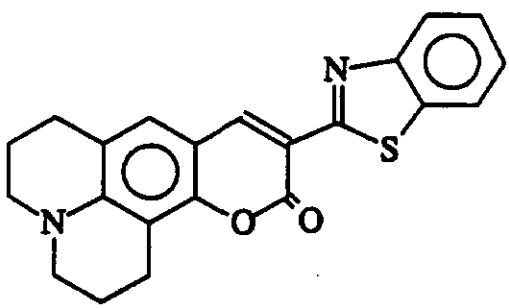

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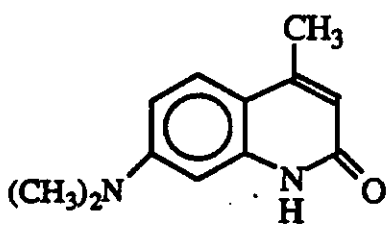

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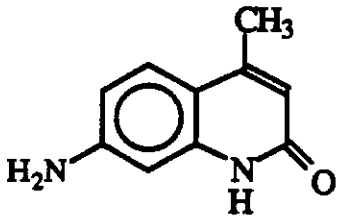

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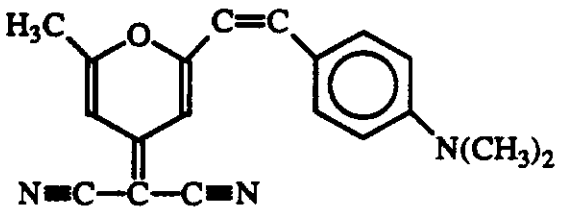

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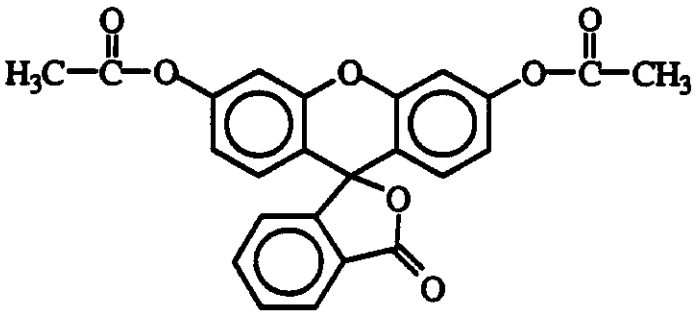

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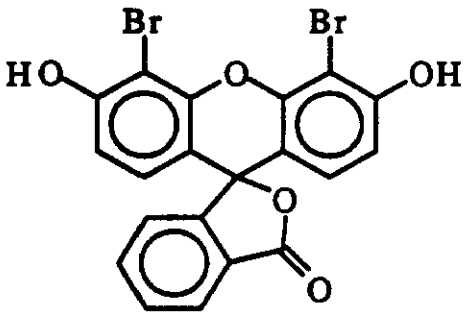

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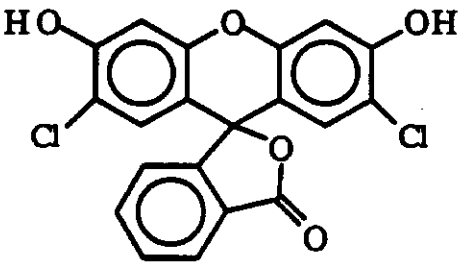

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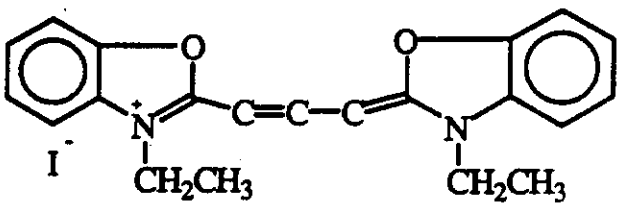

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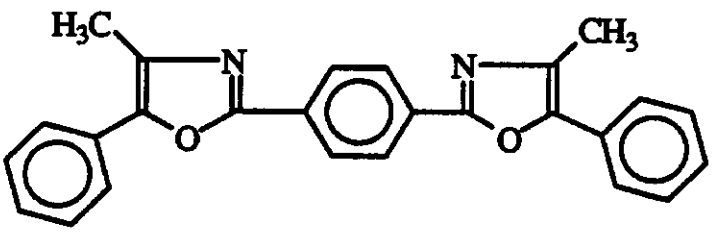

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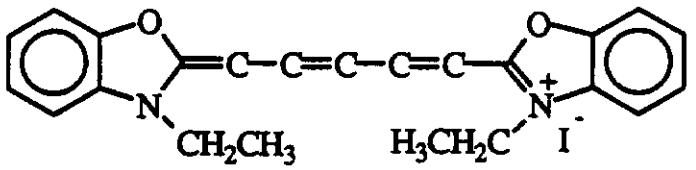

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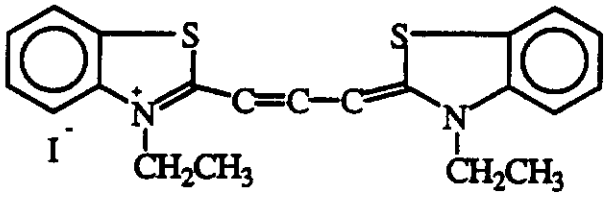

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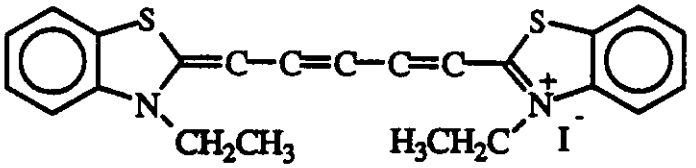

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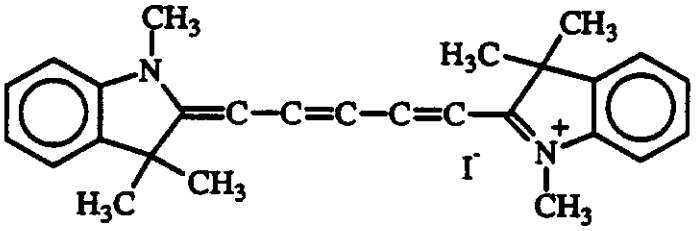

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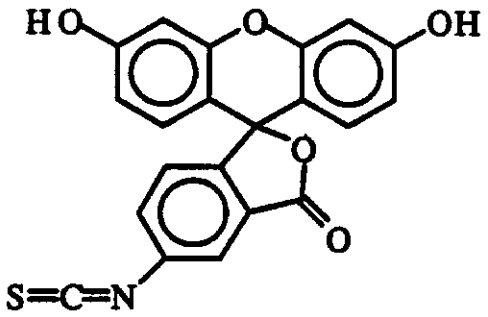

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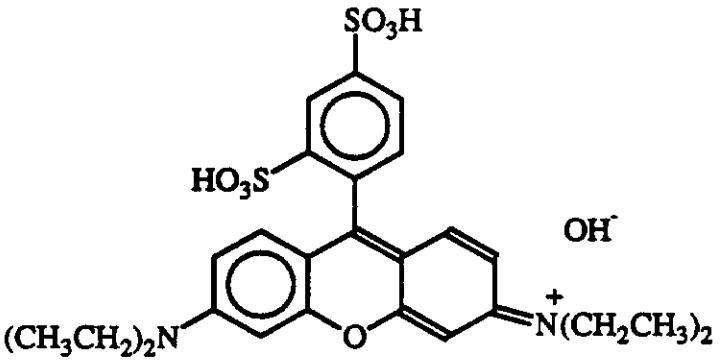

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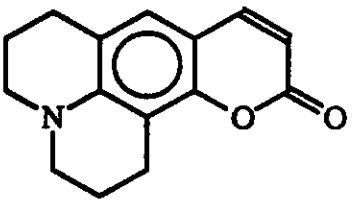

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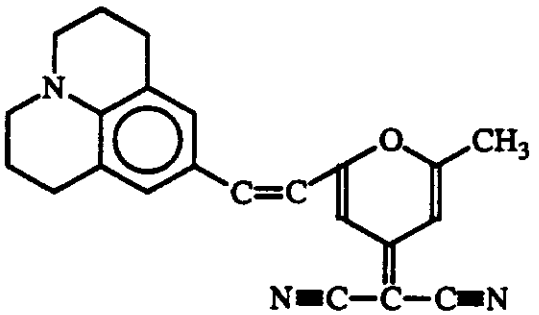

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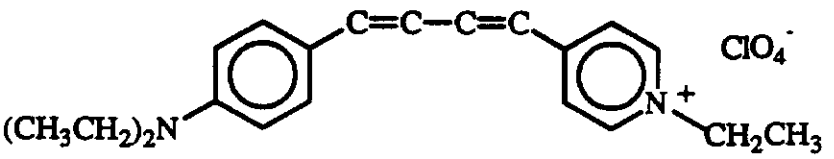

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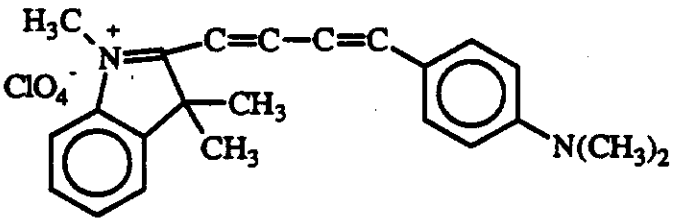

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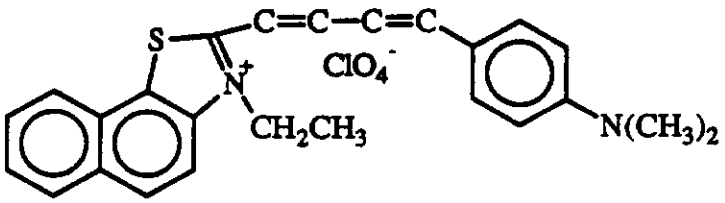

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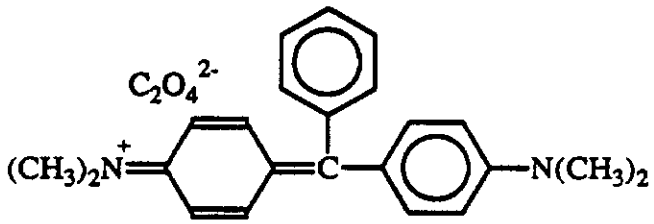

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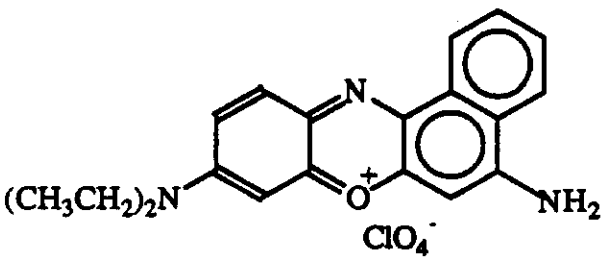

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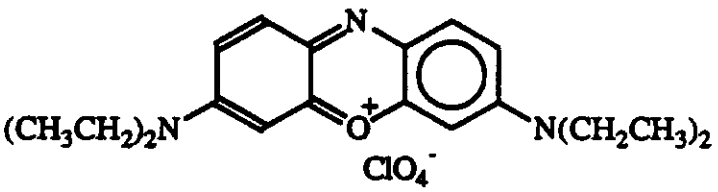

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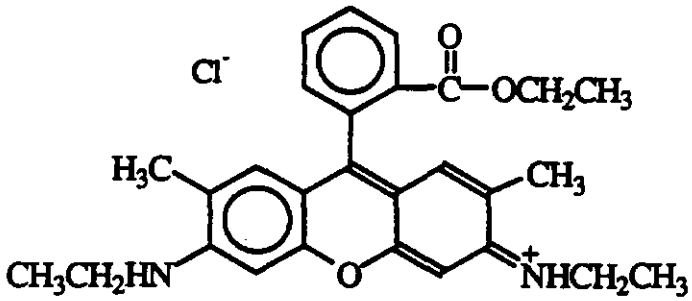

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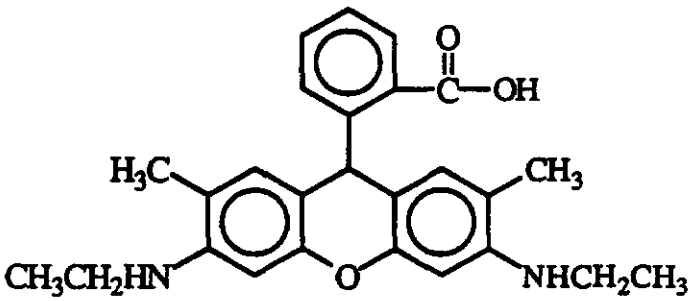

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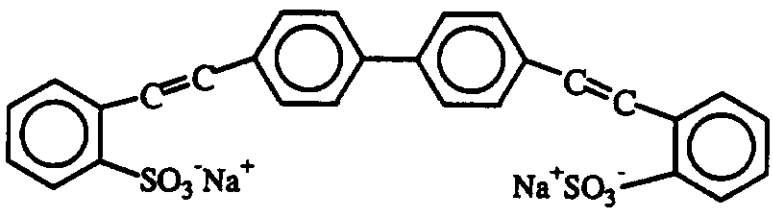

STILBENE 420

APPENDIX B: LIST OF DOPANT NAMES

DOPANTS	CAS #	NAME
ACRIDINE O B	494-38-2	3,6-bis(dimethylamino)acridine
ACRIDINE Y	135-49-9	3,6-diamino-2,7-dimethylacridine hydrochloride
ACRIFLAVINE	8048-52-0	acriflavinium chloride
BBOT	7128-64-5	2,5-bis-5'-tertbutyl-benzoxazolyl-(2')-thiophene
bis-MSB	13280-61-0	1,4-bis(2-methylstyryl)benzene
C35/C481	41934-47-8	7-(diethylamino)-4-(trifluoromethyl)-2H-1-benzopyran-2-one
C153K/C153LP	53518-18-6	2,3,6,7-tetrahydro-9-(trifluoromethyl-1H,5H,11H-[1]benzopyrano[6,7,8-ij]quinolizine-11-one
C314T	113869-06-0	2,3,6,7-tetrahydro-1,1,7,7-tetramethyl-11-oxo-1H,5H,11H(1)benzopyrano(6,7,8-ij)quinolizine-10-carboxylic acid ethyl ester
C338	62669-75-4	1,1-dimethylethyl-2,3,6,7-tetrahydro-11-oxo-1H,5H,11H(1)benzopyrano(6,7,8-ij)quinolizine-10-carboxylate
C478	41175-45-5	2,3,6,7,10,11-hexahydro-1H,5H-cyclopenta[3,4][1]benzopyran[6,7,8-ij]quinolizin-12(9H)-one
C480	41267-76-9	2,3,6,7-tetrahydro-9-methyl-1H,5H,11H-[1]benzopyrano[6,7,8-ij]quinolizine-11-one
C485	53518-14-2	7-(dimethylamino)-4-(trifluoromethyl)-2H-1-benzopyran-2-one
C490	53518-15-3	7-amino-4-(trifouoromethyl)-2H-1-benzopyran-2-one
C498	87331-48-4	2,3,6,7-tetrahydro-10-(methylsulfonyl)-1H,5H,11H-[1]benzopyrano[6,7,8-ij]quinolizin -11-one
C500	52840-38-7	7-(ethylamino)-4-(trifluoromethyl)-2H-1-benzopyran-2-one
C503	55804-70-1	7-(ethylamino)-6-methyl-4-(trifluoromethyl)-2H-1-benzopyran-2-one
C504	55804-66-5	ethyl-2,3,6,7-tetrahydro-11-oxo-1H,5H,11H(1)benzopyrano(6,7,8-ij)quinolizine-10-carboxylate
C510	87349-92-6	2,3,6,7-tetrahydro-10-(3-pyridinyl)-1H,5H,11H-[1]benzopyrano[6,7,8-ij]quinolizin-11-one
C515	41044-12-6	7-(dimethylamino)-3-(1-methyl-1H-benzimidazol-2-yl)-2H-1-benzopyran-2-one
C519	55804-65-4	2,3,6,7-tetrahydro-11-oxo-1H,5H,11H-[1]benzopyrano[6,7,8-ij]quinolizine-10-carboxylic acid
C521	55804-67-6	10-acetyl-2,3,6,7-tetrahydro-1H,5H,11H-[1]benzopyrano[6,7,8-ij]quinolizin-11-one
C522	53518-19-7	6,7,8,9-tetrahydro-9-methyl-4-(trifluoromethyl)-2H-pyrano[3,2-g]quinolin-2-one
C523	55804-68-7	2,3,6,7-tetrahydro-11-oxo-1H,5H,11H-[1]benzopyrano[6,7,8-ij]quinolizine-10-carbonitrile
C525	87331-47-3	10-(2-benzoxazolyl)-2,3,6,7-tetrahydro-1H,5H,11H-[1]benzopyrano[6,7,8-ij]quinolizin-11-one
C535	27425-55-4	3-(1H-benzimidazole-2-yl)-7-(diethylamino)-2H-[1]benzopyran-2-one
C540	38215-36-0	3-(2-benzothiazolyl)-7-(diethylamino)-2H-[1]benzopyran-2-one
C545	85642-11-1	10-(2-benzothiazolyl)-2,3,6,7-tetrahydro-1H,5H,11H-[1]benzopyrano[6,7,8-ij]quinolizin-11-one
CBSTY 3	*	7-dimethylamino-4-methylquinolone-2
CBSTY 124	19840-99-4	7-amino-4-methyl-2(1H)-quinolinone
DCM/DCM2	51325-91-8	[2-[2-[4-(dimethylamino)phenyl]ethenyl]-6-methyl-4H-pyran-4-ylidene]-propanedinitrile
DIACFN	596-09-8	fluorescein diacetate
DIBRFN	596-03-2	4',5'-dibromofluorescein

DOPANTS	CAS #	NAME
DICLFN/FN548	76-54-0	2',7'-dichloro-3',6'-dihydroxy-spiro[isobenzofuran-1(3H),9'-[9H]xanthen-3-one
DMPOPOP	3073-87-8	1,4-bis(4-methyl-5-phenyloxazol-2-yl)-benzene
DOCI	*	diethyloxacarbocyanine iodide
DODCI	14806-50-9	3-ethyl-2-[5-(3-ethyl-2(3H)-benzoxazolyidene)-1,3-pentadienyl]-benzoxazolium iodide
DQOCI	*	*
DTCI	*	diethylthiacarbocyanine iodide
DTDCI	514-73-88	3-ethyl-2-[5-(3-ethyl-2(3H)-benzthiazolyidene)-1,3-pentadienyl]-benzthiazolium iodide
HIDC IODIDE	36536-22-8	2-[5-(1,3-dihydro-1,3,3-trimethyl-2H-indol-2-ylidene)-1,3-pentadienyl]-1,3,3-trimethyl-3H-indolium iodide
ISCNFN	3326-32-7	fluorescein isothiocyanate isomer I
KITON RED 620	2609-88-3	N-[6-(diethylamino)-9-(2,4-disulfophenyl)-3H-xanthen-3-ylidene]-N-ethyl-ethanaminium hydroxide
LD490	58336-35-9	2,3,6,7-tetrahydro-1H,5H,11H,[1]benzopyrano[6,7,8-ij]-quinoliz-11-one
LD688	51325-95-2	2-methyl-6-[2-(2,3,6,7-tetrahydro-1H,5H-benzo[ij]quinolizin-9-yl)ethenyl]-4H-pyran-4-ylidene]-propanedinitrile
LDS722	89846-21-9	4-[4-[4-(dimethylamino)phenyl]-1,3-butadienyl]-1-ethyl-pyridinium perchlorate
LDS730	76433-27-7	2-[4-[4-(dimethylamino)phenyl]-1,3-butadienyl]-1,3,3-trimethyl-3H-indolium perchlorate
LDS750	89872-07-1	2-[4-[4-(dimethylamino)phenyl]-1,3-butadienyl]-3-ethylnaphtho[2,1-d]thiazoliumperchlorate
MALACHITE GREEN	18015-76-4	N-[4-[[4-(dimethylamino)phenyl]phenylmethylene]-2,5-cyclohexadien-1ylidene-N-methylmethanaminium ethanedioate(2:2:1)
NILE BLUE	53340-16-2	5-amino-9-(diethylamino)-benzo[a]phenoxazin-7-ium perchlorate
OXAZINE 725	24796-94-9	3,7-bis(diethylamino)-phenoxazin-5-ium perchlorate
PYRIDIN1	*	*
RHODAMINE 6G	989-38-8	9-(2-(ethoxycarbonyl)phenyl)-3,6-bis(ethylamino)-2,7-dimethylxanthylium chloride
RHODAMINE575	25152-49-2	2-[6-(ethylamino)-3-(ethylamino)-2,7-dimethyl-3H-xanthen-9-yl]-benzoic acid
STILBENE 420	27344-41-8	2,2'-([1,1'-biphenyl]-4,4'-diyldi-2,1-ethenediyl)bis-benzenesulfonic acid disodium salt

* information not available in MSDS