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EFFECT OF SIMULATED SPACE RADIATION ON SELECTED OPTICAL MATERIALS

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16. Abstract

The effect of simulated Nimbus spacecraft orbital (1100 km, circular, and polar) radiation on wide-bandpass glass filters, narrow-bandpass thin-film interference filters, and several fused silicas was determined by transmittance measurements over the 200- to 3400-nm wavelength region. No changes were observed in the filters, which were shielded with fused silica during irradiation, after exposure to a 1-year equivalent orbital dose of electrons, nor were changes observed in the fused silicas after the same electron exposure plus a 1-year equivalent dose of protons. Exposure to a ½-year equivalent dose of solar ultraviolet radiation, however, caused a significant degradation in the transmittance of two ultraviolet-transmitting interference filters but had no effect on two colored-glass filters that transmitted in the visible and near-infrared regions. As a result of the ultraviolet exposure, the fused silicas exhibited losses of several percent over the 200- to 300-nm wavelength region.

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INTRODUCTION

Current emphasis on meteorological and earth resources satellites has brought about a significant increase in the use of optical materials in space. This, in turn, has required an increased awareness of the effect of the space environment on such materials. Reflectance and transmittance, for example, can be severely affected by particulate and solar radiation impinging on optical elements.

Results are given in this paper of the effect of electron, proton, and ultraviolet radiation on the transmittance of various fused silicas, colored-glass filters, and thin-film interference filters proposed for use in the optics of the Earth Radiation Budget (ERB) experiment. The ERB experiment package is to be flown on a Nimbus spacecraft. The experiment will simultaneously measure the quantity of electromagnetic radiation emanating from the earth and that incident upon it. Optical materials will be utilized in the experiment package in a number of "earth-looking" channels, one of which will use a wide-bandpass glass filter, and "sun-looking" channels which use either wide-bandpass glass filters or narrow-bandpass interference filters. The filters used in all channels will be shielded by fused-silica windows.

The fused-silica shielded filters were exposed to electrons and ultraviolet radiation; the fused silicas were exposed to protons as well. The particle fluences used in this study were equivalent to those that will be experienced by the satellite during 1 year in orbit. In most cases the filters and the fused silicas were exposed to ultraviolet radiation equivalent to ½ year in orbit. In some instances, however, the exposure was somewhat less than or greater than ½ year in orbit.

All irradiations were performed at a pressure of 1×10^{-5} torr or less. Transmittance measurements were made in air between 5 and 24 hours after irradiation.

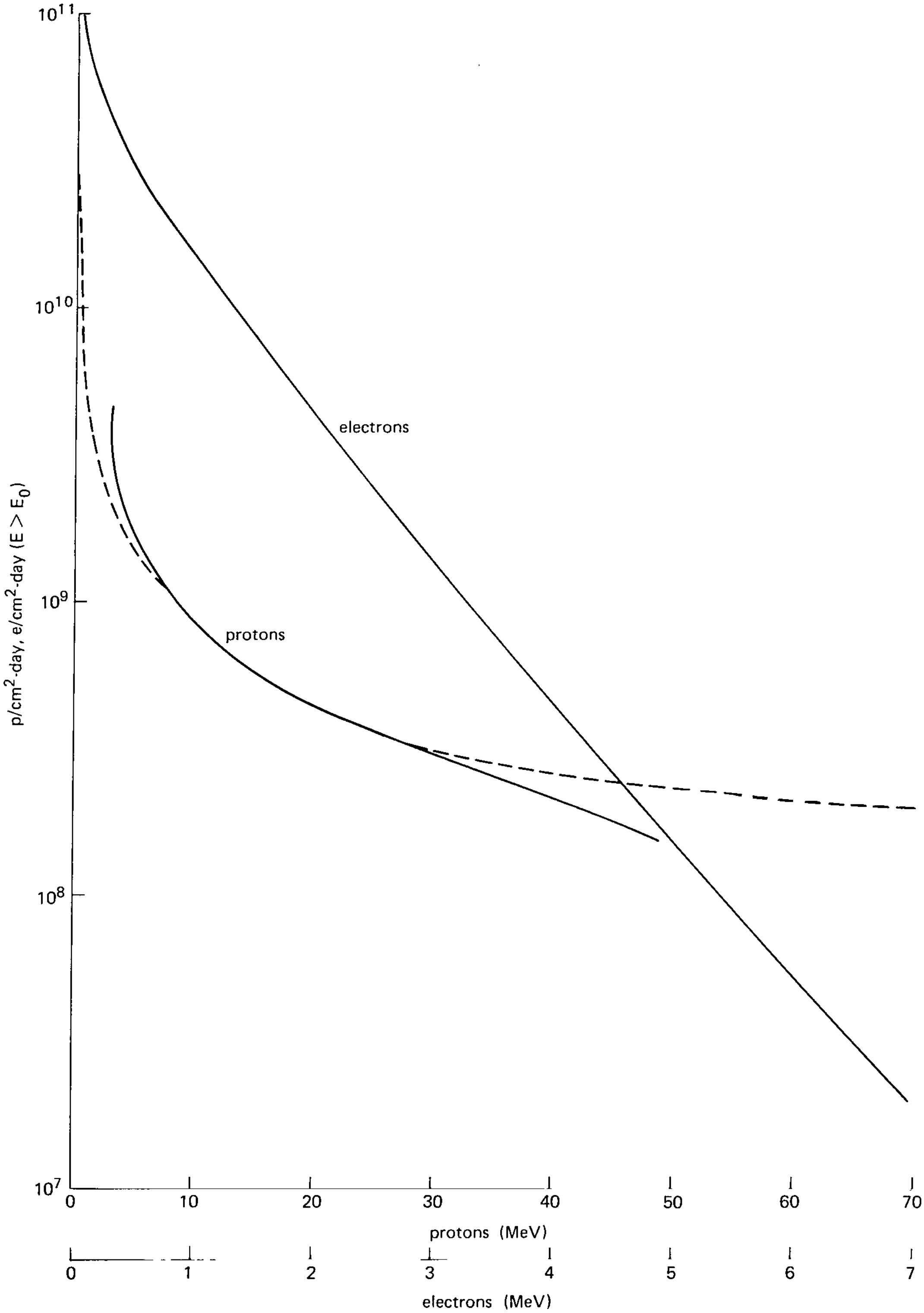

Figure 1—Electron and proton fluxes encountered in the Nimbus orbit.

RADIATION TEST LEVELS

Charged-Particle Radiation

Data on integral flux versus particle energy for a 1100-km polar orbit (Nimbus orbit) were obtained from theoretical studies made at NASA-GSFC;* these data are shown in Figure 1. To simulate as closely as possible the actual space radiation spectrum, electron energy levels of 0.3, 0.5, 1.0, and 1.5 MeV and proton energy levels of 0.5, 1.5, and 2.0 MeV were utilized in this study.

The estimated maximum yearly fluence at each of the above energies was determined from the flux-energy data and was used in conjunction with an obscuration factor of 0.5 to calculate dosage. This obscuration factor took into account the partial blocking out of radiation as a result of optical component positioning within the experiment housing. The energies and fluences for the particle irradiations are given in Tables 1 and 2.

Ultraviolet Radiation

The solar-viewing channels will receive approximately 2200 hours of solar radiation in 1 year, and the earth-viewing channels somewhat less. All of the materials investigated in this study were proposed for use in the solar-viewing channels; some were proposed for both solar- and earth-viewing channels. Most of the materials were irradiated at 2.0 ultraviolet solar constants (UVSC) for a period of 550 hours, or 1100 equivalent ultraviolet solar hours (EUVSH). This approximates ½ year in orbit. Some materials, however, were irradiated at 3.5 UVSC for equivalent periods of much less than a year in orbit, in some instances this shorter period being sufficient to indicate that the material would be unsatisfactory for the intended application.

Table 1—Electron irradiation test levels.

Energy (MeV)	Electron Fluence (e/cm^2)
0.3	1.4×10^{13}
0.5	7.3×10^{12}
1.0	3.7×10^{12}
1.5	1.6×10^{12}

Table 2—Proton irradiation test levels.

Energy (MeV)	Proton Fluence (p/cm^2)
0.5	3.3×10^{11}
1.5	3.8×10^{10}
2.0	1.7×10^{10}

*E. Stassinopoulos, private communication.

MATERIALS AND EXPERIMENTAL PROCEDURE

The materials irradiated, samples of which were provided by the National Environmental Satellite Service of the National Oceanic and Atmospheric Administration, were—

(1) Dynasil 1000 (fused silica),

(2) Suprasil-W (fused silica),

(3) Corning 7940 (fused silica),

(4) Infrasil II (fused silica),

(5) Schott Filter Glass OG530 (wide bandpass),

(6) Schott Filter Glass RG695 (wide bandpass),

(7) Interference Filter No. 1 (250 to 300 nm),

(8) Interference Filter No. 4 (350 to 450 nm),

(9) Interference Filter No. 5 (400 to 500 nm),

(10) Interference Filter No. 7 (700-nm cut-on).

The Dynasil 1000 samples were obtained from Dynasil Corporation (United States). Corning 7940 is commercially available from Corning Glass Works (United States). The Suprasil-W, Infrasil II, and Schott filter glasses were manufactured by Engelhard-Heraeus-Schott (West Germany). The interference filters used Dynasil 1000 substrates and were produced by Thin Films Industries (United States).

Schott filter glasses OG530 and RG695 and the interference filters were placed behind 3.1-mm of Corning 7940 fused silica during electron and ultraviolet exposure. Since the penetration range of the highest energy electrons (1.5 MeV) is 2.5 mm in fused silica (Reference 1), the Corning 7940 shielding was sufficient to prevent any penetration by the electrons. Any significant damage that might occur in the case of electron exposure, therefore, would be attributable to bremsstrahlung.

The penetration of 2.0-MeV protons into fused silica is 0.03 mm (Reference 1). Since this penetration is relatively insignificant and since bremsstrahlung produced by protons is negligible, it was not considered necessary to expose the filters to proton irradiation.

The samples were measured for transmittance before and after irradiation. All samples, except the interference filters, were cleaned with toluene before the optical measurements were made; the interference filters were wiped with lens tissue.

Charged-Particle Irradiation

Samples were exposed in a vacuum of 1×10^{-5} torr to electrons from a Van de Graaff accelerator. The beam flux was kept at 10^{11} e/cm^2-s for all exposures. Samples exposed to protons were in a vacuum of 1×10^{-6} torr with a beam flux of 10^{10} p/cm^2-s. Transmittance measurements in all cases were made within 5 hours after irradiation.

Ultraviolet Irradiation

Upon termination of the charged-particle irradiation, the samples were exposed to ultraviolet radiation. During this irradiation, the samples were maintained at a temperature of approximately 288 K in a vacuum of 1×10^{-7} torr. Exposure was at 2.0 UVSC from a xenon lamp for 550 hours to give 1100 EUVSH. Corning 7940, Suprasil-W, and Infrasil II samples were exposed in vacuum to ultraviolet radiation from a mercury arc at 3.5 UVSC. After irradiation the samples were kept cool and dry in a refrigerated desiccator until the transmittance measurements were made. Before the measurements were carried out, the samples were allowed to come to room temperature. All measurements were made within 24 hours after irradiation.

Optical Transmittance Measurements

The transmittances of the fused silicas and the Schott glass filters were measured over the 200- to 3400-nm wavelength region. These measurements were made with a Beckmann DK-1A spectrophotometer which was accurate to within two transmittance percentage points. The interference filters were measured over their respective ranges with a Cary-14 spectrophotometer which was accurate to within one-half of a transmittance percentage point.

EXPERIMENTAL RESULTS

Dynasil 1000

Within the accuracy of the transmittance instrument, Dynasil 1000 was not affected by electron or proton irradiation at the levels encountered in the Nimbus orbit over a 1-year period. In this connection, Heath and Sacher (Reference 2) found, in fused silica (described as Dynasil optical grade), significant degradation below 300 nm caused by 1- and 2-MeV electron bombardment; however, the fluence used in their study (2×10^{14} e/cm^2) was larger than in the present case.

Ultraviolet irradiation, on the other hand, significantly decreased the transmittance of Dynasil 1000 in the 200- to 400-nm wavelength region, as is shown in Figure 2. The cumulative effects on transmission of electron, proton, and ultraviolet irradiation are shown in Figure 3.

Suprasil-W

Electrons of 1.0-MeV energy had no effect on Suprasil-W during an exposure equivalent to approximately 1/3 year in orbit (i.e., 1×10^{13} e/cm^2). After a total dose of 1×10^{14} e/cm^2, however, significant transmission loss occurred from 200 to 300 nm (Figure 4). Irradiation by 1.5-MeV electrons to 1×10^{14} e/cm^2 caused a considerable loss in transmittance at 250 nm (Figure 5). This loss approximates that of the fused silica evaluated by Heath and Sacher (Reference 2). Upon exposure to ultraviolet radiation, the material exhibited a definite loss in transmittance between 200 and 400 nm (Figure 6). It appears that the degradation increases linearly up to about 1200 EUVSH and then begins to level off.

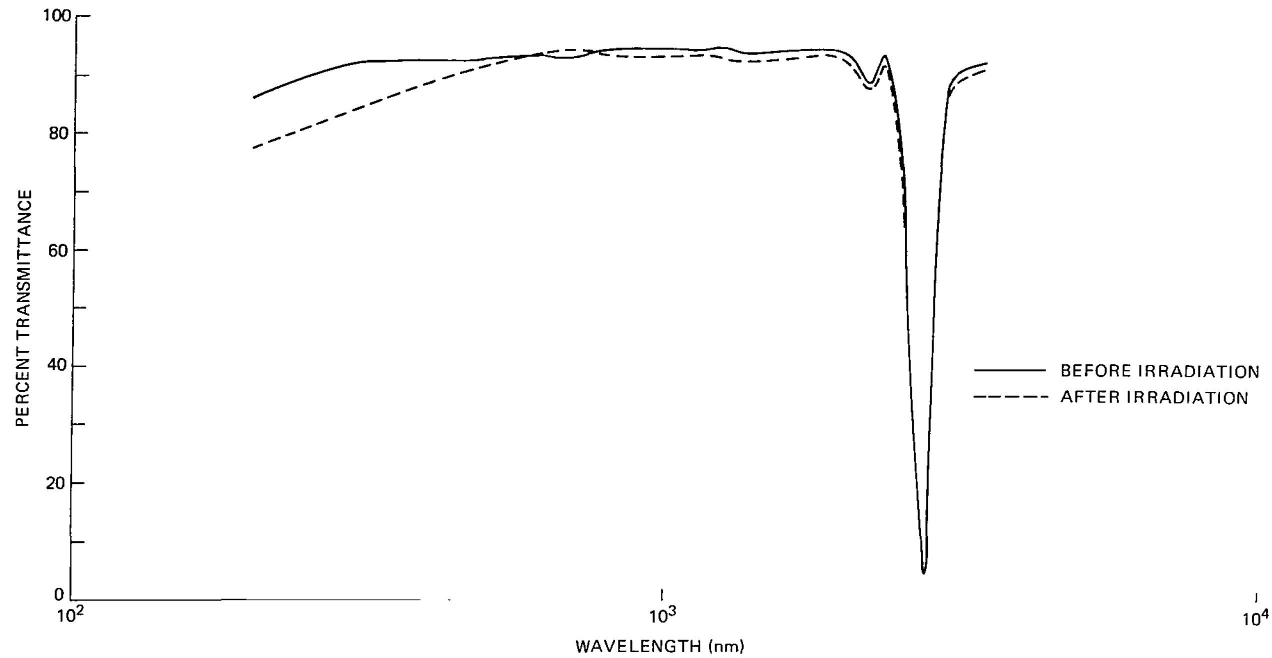

Figure 2—Transmittance of Dynasil 1000 before and after ultraviolet irradiation at 2.0 UVSC for 1100 EUVSH.

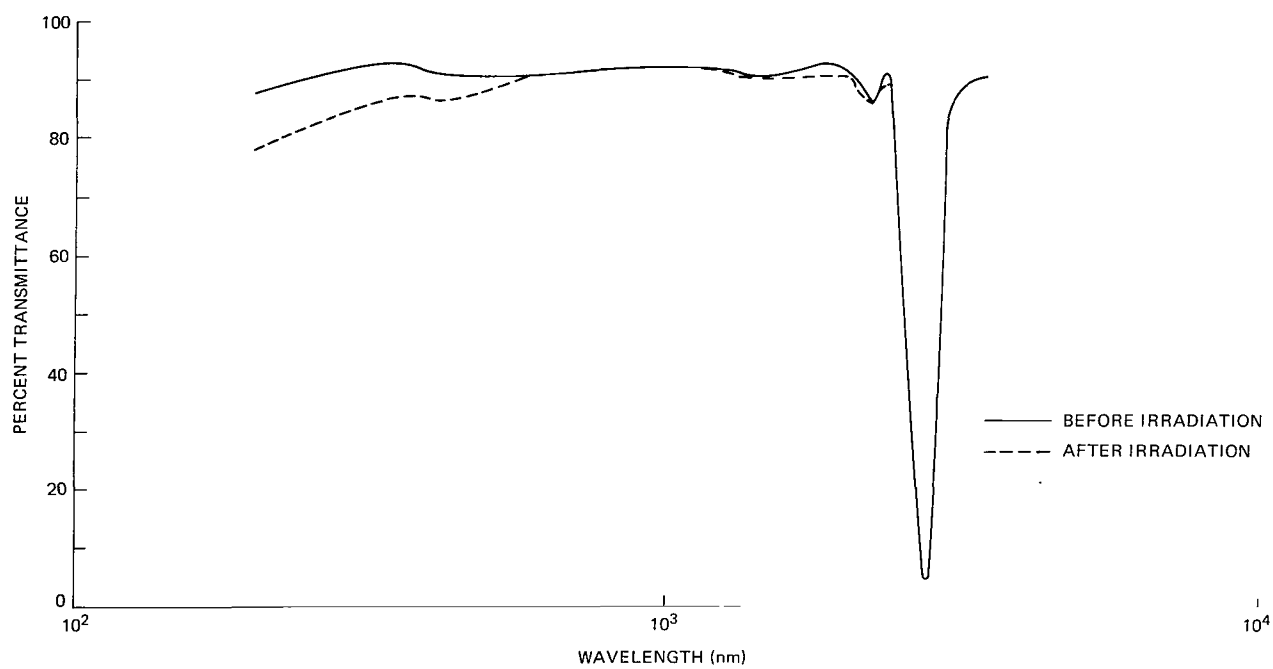

Figure 3—Transmittance of Dynasil 1000 before and after irradiation by electrons of energies 0.3, 0.5, 1.0, and 1.5 MeV to a total flux of 2.7 X 10^{13} e/cm^2, plus protons of energies 0.5, 1.5, and 2.0 MeV to a total flux of 3.9 X 10^{11} p/cm^2, plus ultraviolet radiation at 2.0 UVSC for 1100 EUVSH.

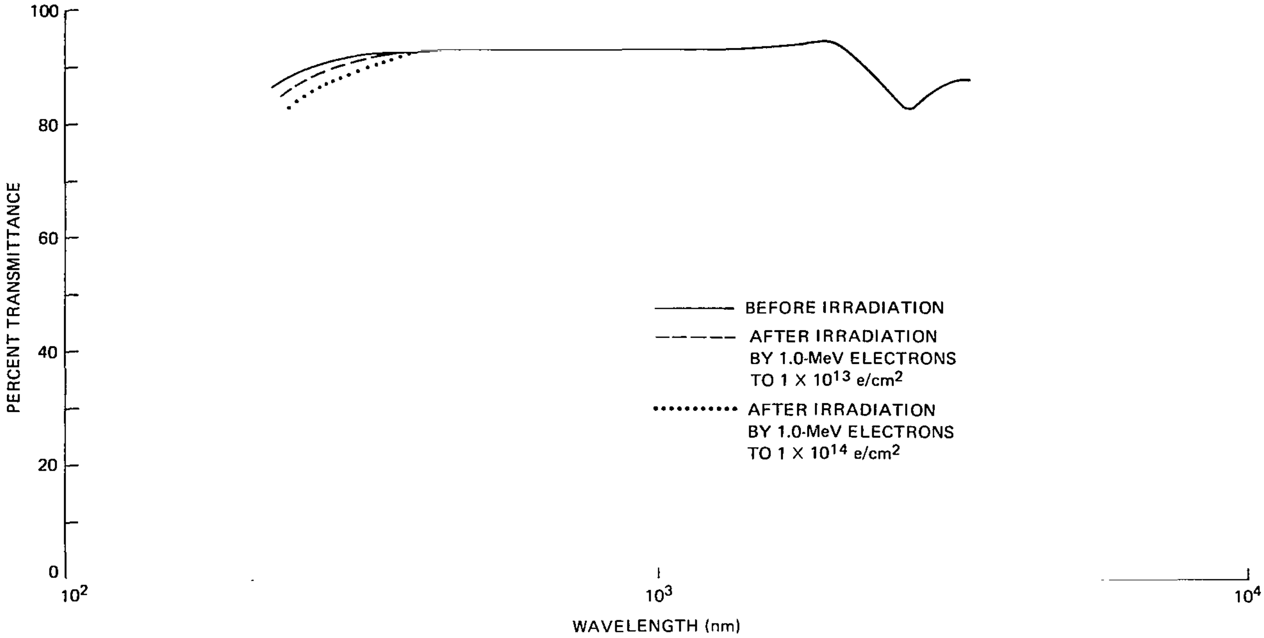

Figure 4—Transmittance of Suprasil-W before and after irradiation by electrons of 1.0-MeV energy to a total flux of 1.0×10^{13} e/cm^2 and after irradiation by electrons of 1.0-MeV energy to a total flux of 1.0×10^{14} e/cm^2.

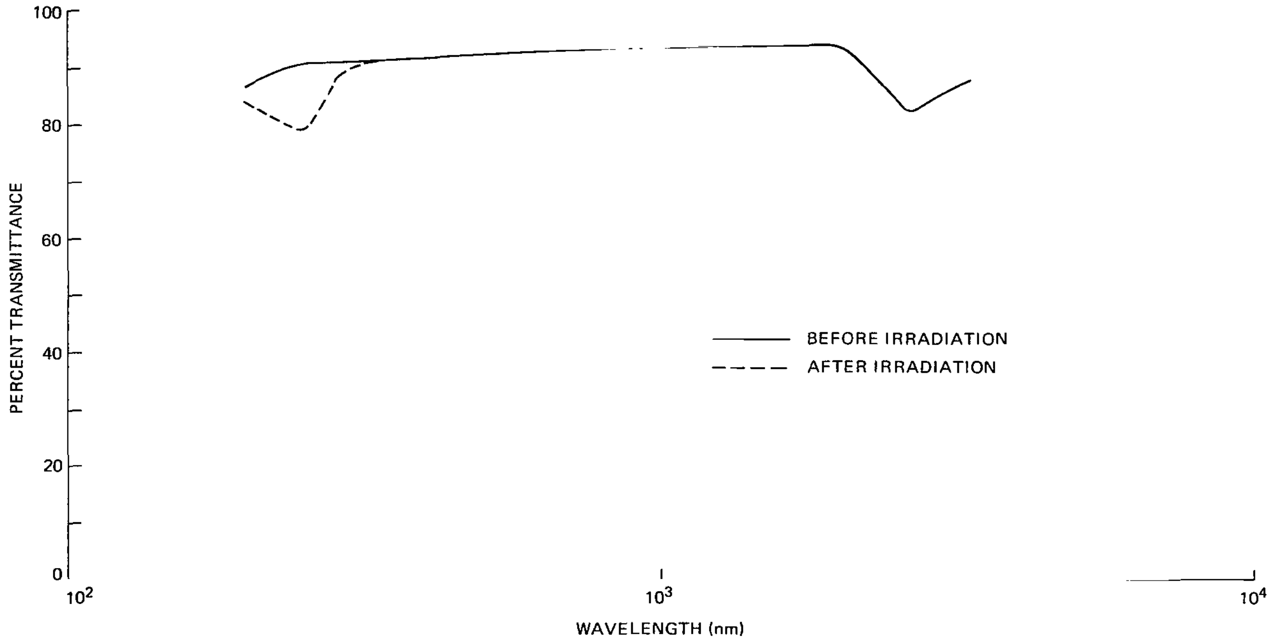

Figure 5—Transmittance of Suprasil-W before and after irradiation by electrons of 1.5-MeV energy to a total flux of 1.0×10^{14} e/cm^2.

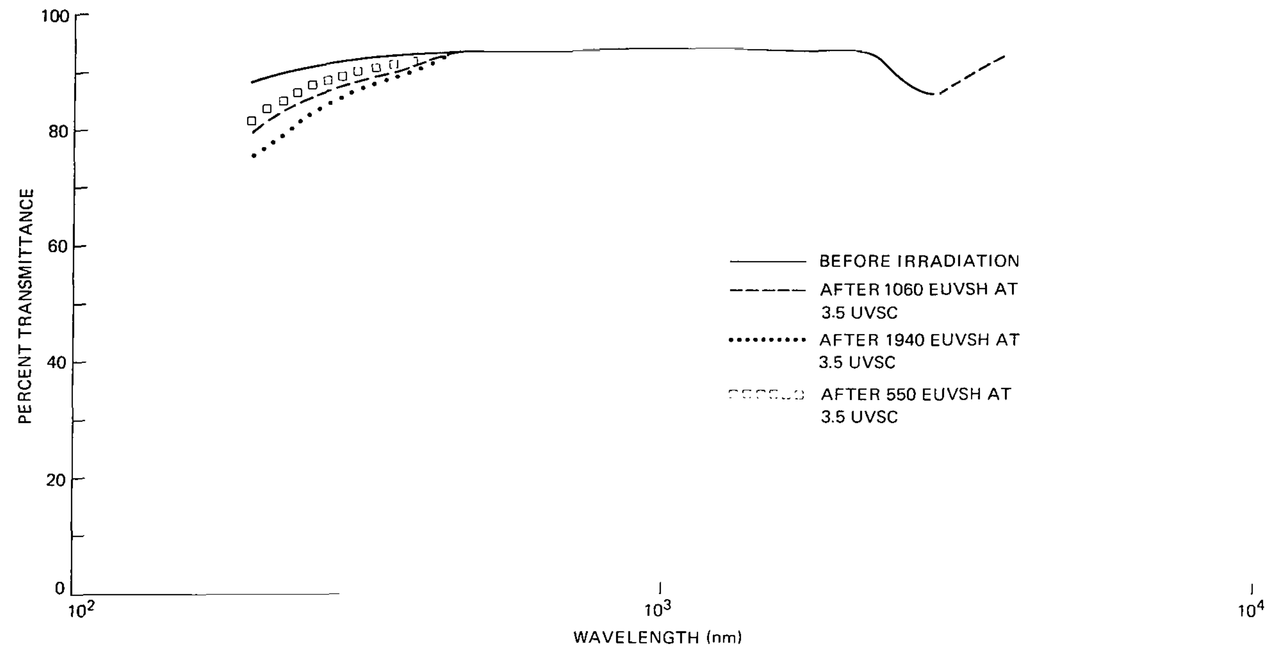

Figure 6—Transmittance of Suprasil-W before and after ultraviolet irradiation at 3.5 UVSC for 550, 1060, and 1940 EUVSH.

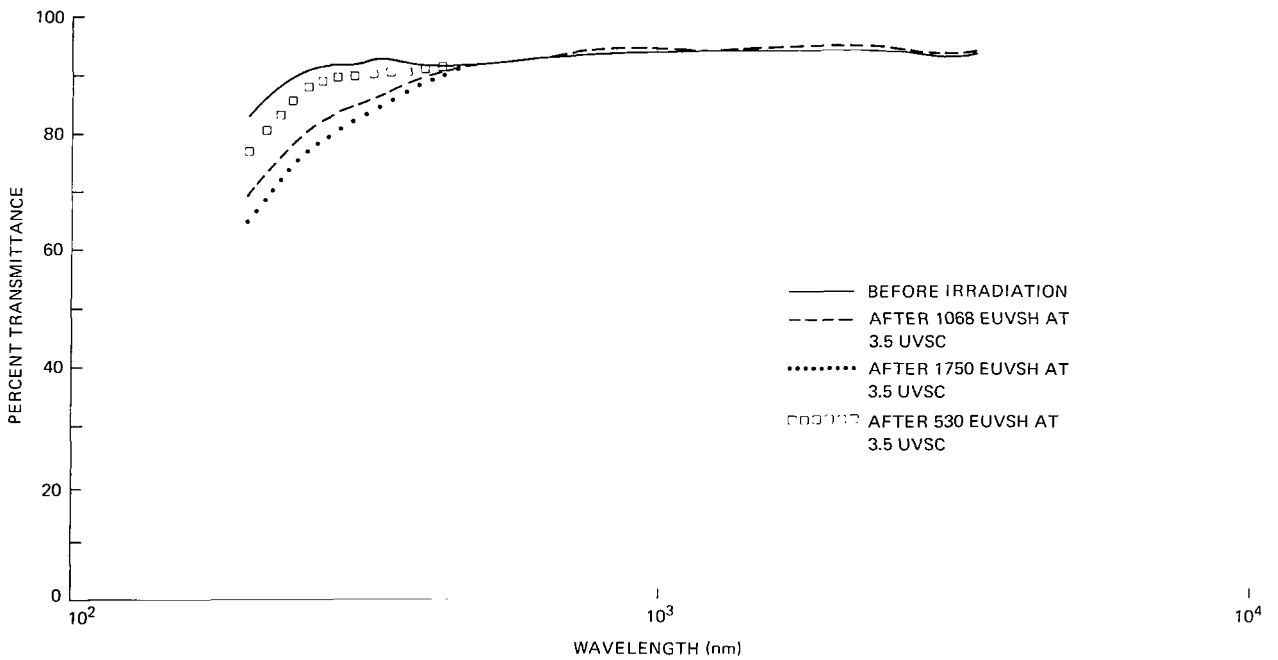

Figure 7—Transmittance of Infrasil II before and after ultraviolet irradiation at 3.5 UVSC for 530, 1068, and 1750 EUVSH.

Infrasil II

Infrasil II fused silica was exposed to ultraviolet irradiation only. It exhibited a significant decrease in transmittance, as is shown in Figure 7.

Corning 7940

Samples of Corning 7940 fused silica were exposed to charged particles and to ultraviolet irradiation, although transmittance data were obtained only after the latter exposure. The material was exposed at rates of 2.0 and 3.5 UVSC; the results are shown in Figures 8 and 9, respectively.

Schott Colored-Glass Filters

The spectral transmittances of Schott Filters OG530 and RG695, when suitably shielded with fused silica, exhibited no significant changes as a result of electron and/or ultraviolet exposure.

Interference Filters

The results of irradiation on the interference filters are shown in Figures 10 through 13. Filters No. 1 (Figure 10) and No. 4 (Figure 11) showed a significant change after ultraviolet irradiation. There was a decrease of approximately 72 percent in the transmittance peak of Filter No. 1 and a 28-percent decrease in the peak height of Filter No. 4 after an exposure of 1100 EUVSH. Figures 10 and 11 also show transmittance measurements made 170 hours after irradiation. These measurements were made to determine if annealing of the radiation damage took place during that period. Within the reproducibility of the spectrophotometer, there does not appear to be any annealing effect. The samples had been kept at approximately 281 K in a desiccator during the postirradiation period. No changes due to irradiation were observed in Filter No. 5 (see Figure 12) or Filter No. 7 (see Figure 13).

CONCLUSIONS

No significant changes occurred in the transmittances of any of the fused silicas as a result of exposure to electron and proton radiation equivalent to 1 year in space; nor was there any change in the filters (shielded with fused silica), which were exposed to electrons only. The study shows, however, that exposure to electron fluences of 2×10^{14} e/cm^2 or greater with electron energies of 1.0 MeV and higher can be expected to cause significant transmittance losses in fused silica. For electron energies up to 1.5 MeV, a 3.1-mm-thick fused-silica shield sufficiently protects both wide-bandpass glass and narrow-bandpass interference filters.

Resistance to ultraviolet radiation appears to be the most important factor in the selection of a fused silica for space use. Figure 14, a plot of transmittance change at 250 nm versus exposure hours, is illustrative. Points *C* and *D* represent changes experienced by Corning 7940 and Dynasil 1000, respectively, after 1100 EUVSH at 2.0 UVSC. As the figure indicates, Suprasil-W appears to be the most resistant to ultraviolet irradiation, followed by Corning 7940. Dynasil 1000 and Infrasil II exhibit much greater degradation.

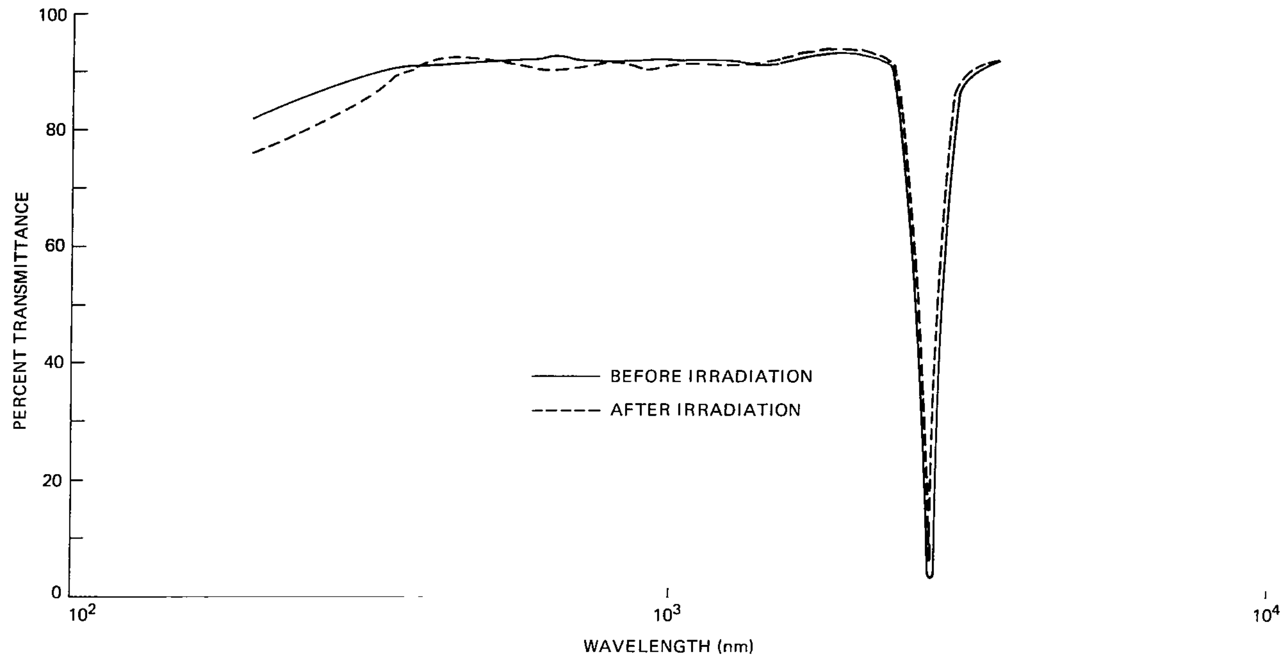

Figure 8—Transmittance of Corning 7940 before and after ultraviolet irradiation at 2.0 UVSC for 1100 EUVSH.

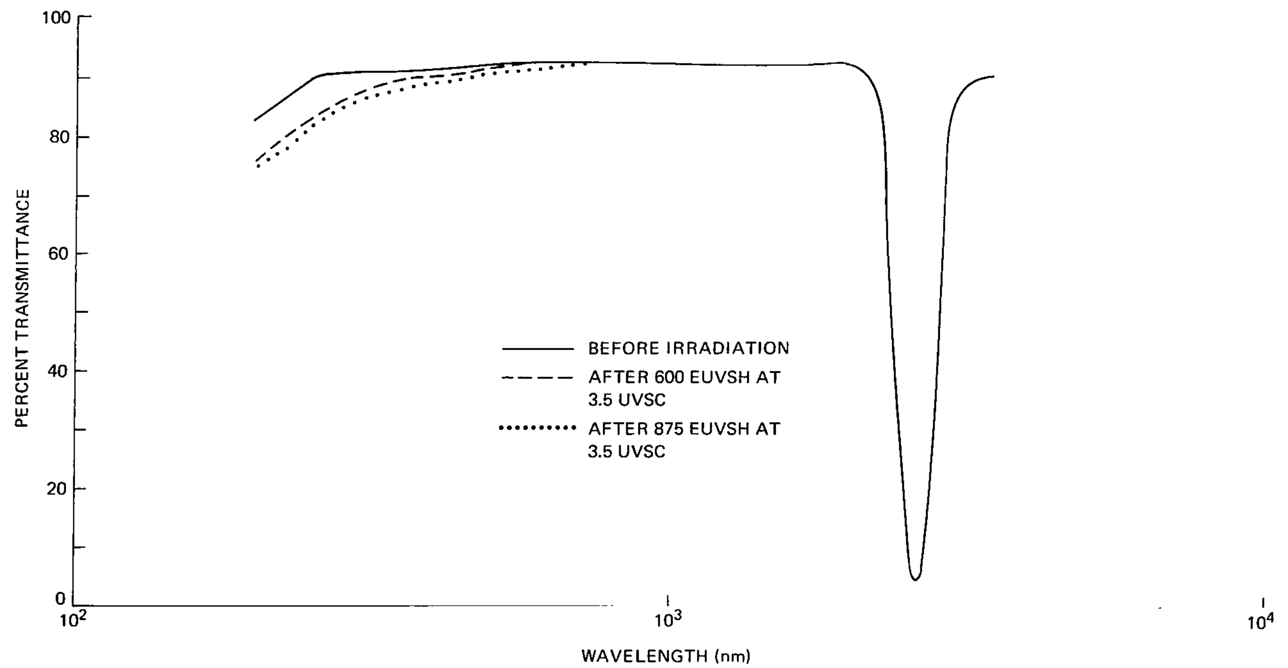

Figure 9—Transmittance of Corning 7940 before and after ultraviolet irradiation at 3.5 UVSC for 600 and 875 EUVSH.

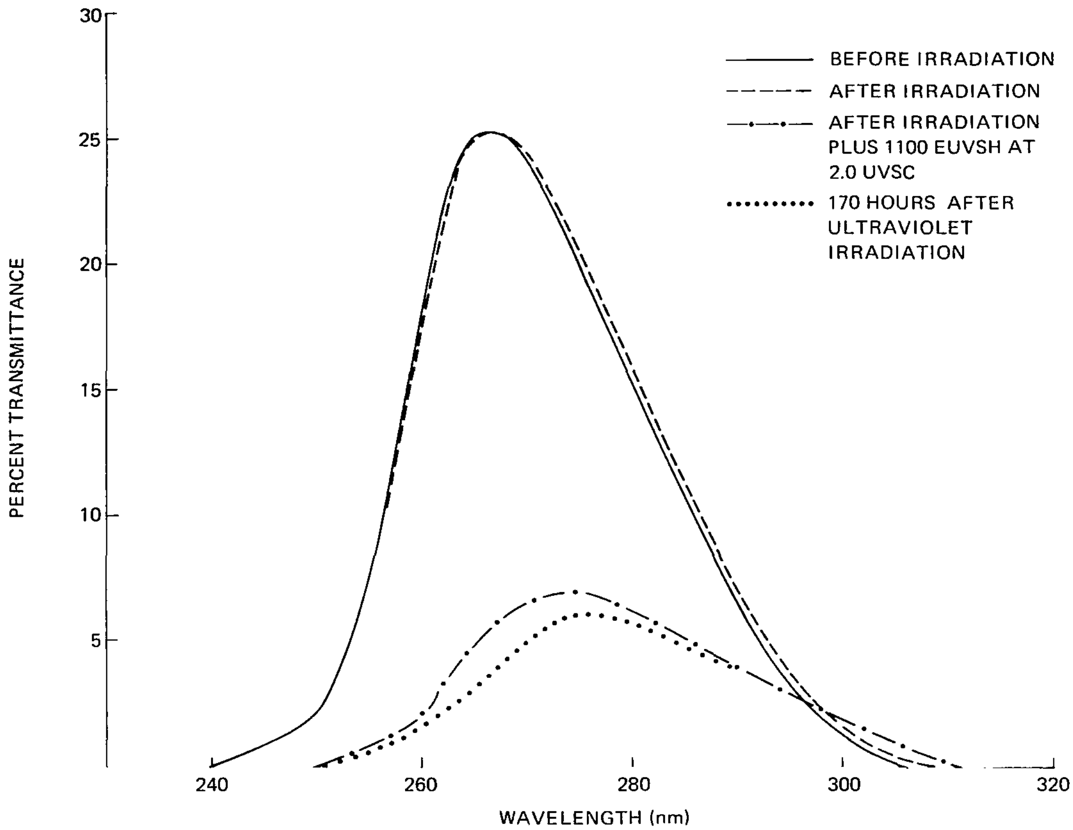

Figure 10—Transmittance of Interference Filter No. 1 (250 to 300 nm) before and after irradiation by electrons of energies 0.3, 0.5, 1.0, and 1.5 MeV to a total flux of 2.7 X 10^{13} e/cm^2, and after irradiation by the above electrons plus ultraviolet radiation at 2.0 UVSC for 1100 EUVSH. Measurements were also made 170 hours after the ultraviolet irradiation. The filter was shielded from direct radiation by 3.1 mm of fused silica.

Schott Filters OG530 and RG695, when sufficiently shielded by fused silica against electrons and protons, are suitable wide-bandpass filters.

Interference Filters No. 1 and No. 4 exhibited far too much ultraviolet degradation for use in the solar channels of the ERB experiment. The decrease in transmittance observed in the Dynasil 1000 samples as a result of the ultraviolet irradiation is not sufficient to account for the losses exhibited by these filters, which have Dynasil 1000 substrates and protective covers. Filter No. 1 was composed of layers of aluminum and cryolite with a thorium-fluoride overcoat. Filter No. 4 was composed of layers of silver and cryolite with no overcoat. In both cases, the protective covers were attached to the filter and separator rings with a neoprene adhesive.

Although no experiments were carried out to determine the exact cause of the degradation, it seems reasonable to conclude that it is due to the thin-film materials and/or the neoprene adhesive

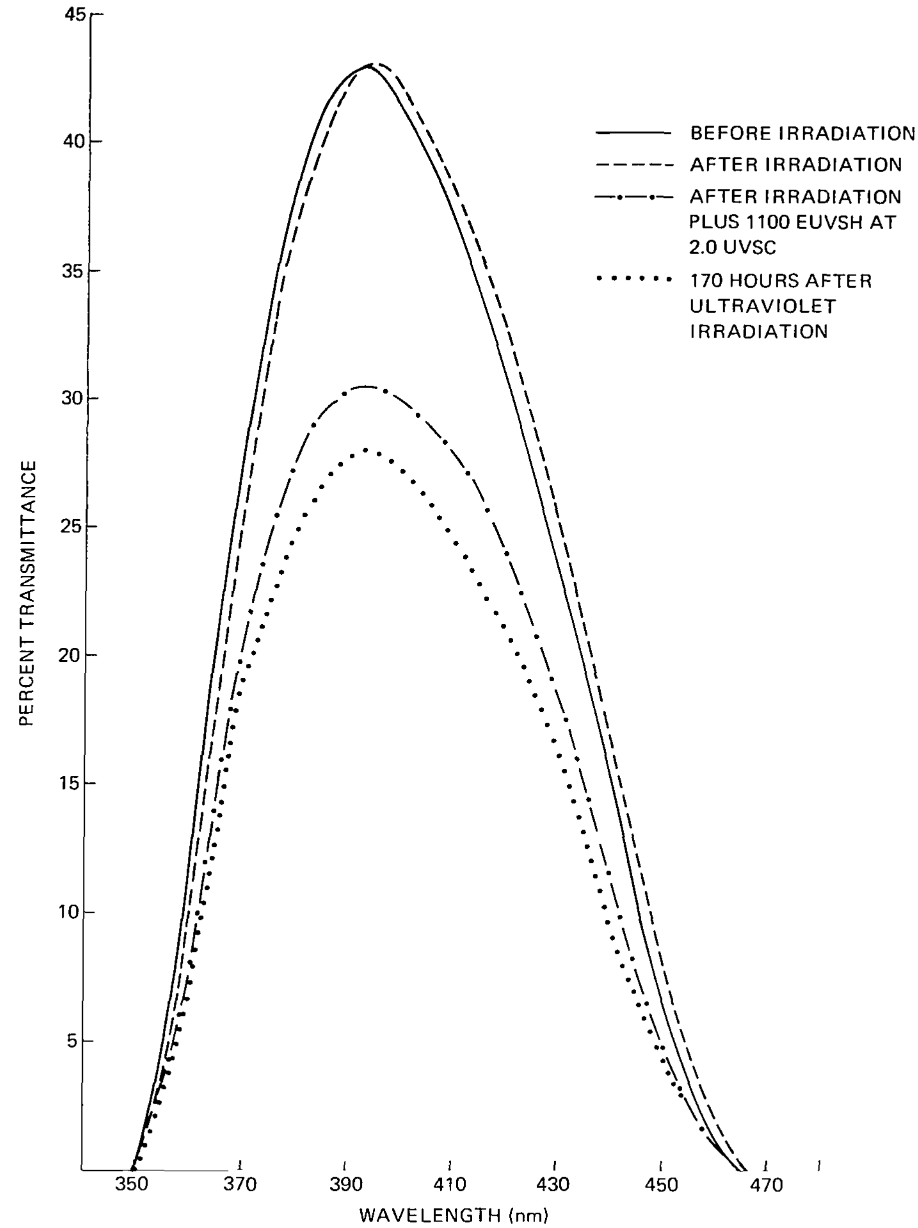

Figure 11—Transmittance of Interference Filter No. 4 (350 to 450 nm) before and after irradiation by electrons of energies 0.3, 0.5, 1.0, and 1.5 MeV to a total flux of 2.7×10^{13} e/cm^2, and after irradiation by the above electrons plus ultraviolet radiation at 2.0 UVSC for 1100 EUVSH. Measurements were also made 170 hours after the ultraviolet irradiation. The filter was shielded from direct radiation by 3.1 mm of fused silica.

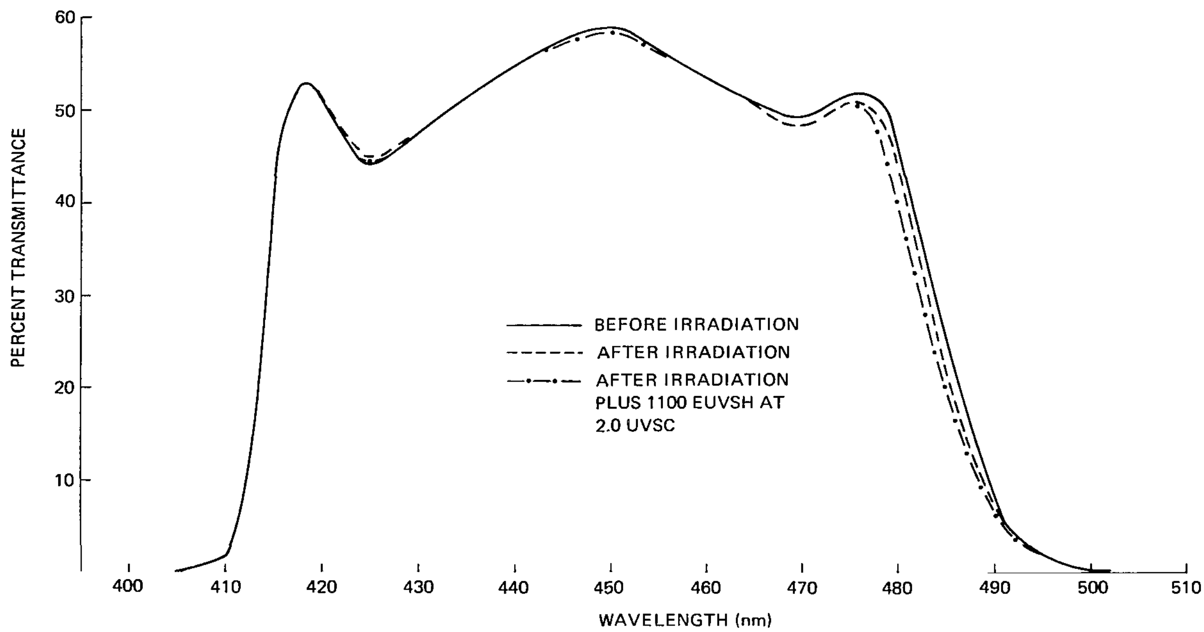

Figure 12—Transmittance of Interference Filter No. 5 (400 to 500 nm) before and after irradiation by electrons of energies 0.3, 0.5, 1.0, and 1.5 MeV to a total flux of 2.7×10^{13} e/cm^2, and after irradiation by the above electrons plus ultraviolet radiation at 2.0 UVSC for 1100 EUVSH. The filter was shielded from direct radiation by 3.1 mm of fused silica.

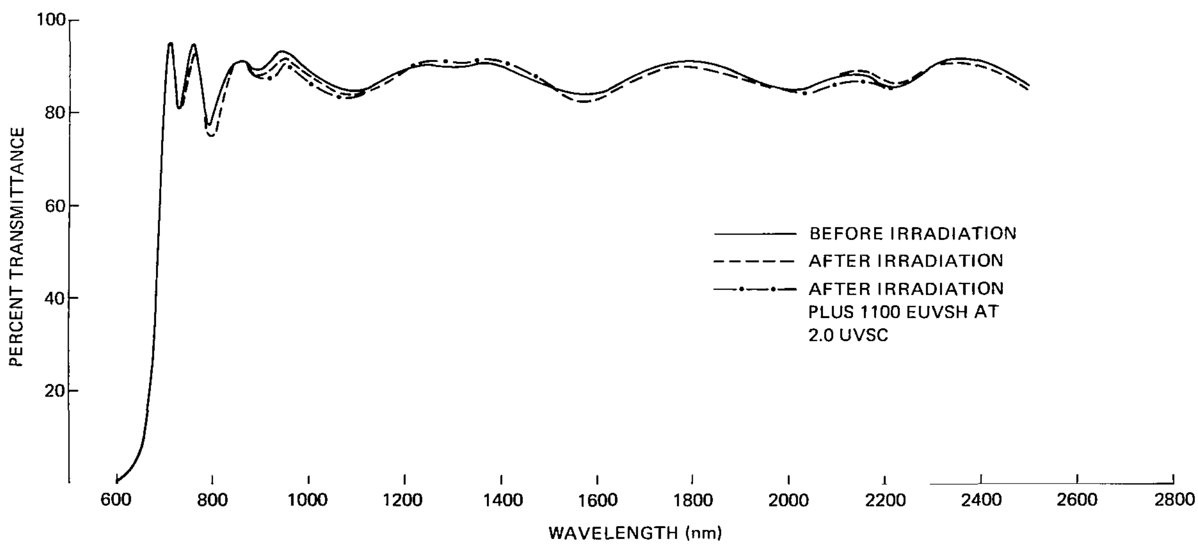

Figure 13—Transmittance of Interference Filter No. 7 (700-nm cut-on) before and after irradiation by electrons of energies 0.3, 0.5, 1.0, and 1.5 MeV to a total flux of 2.7×10^{13} e/cm^2, and after irradiation by the above electrons plus ultraviolet radiation at 2.0 UVSC for 1100 EUVSH. The filter was shielded from the direct radiation by 3.1 mm of fused silica.

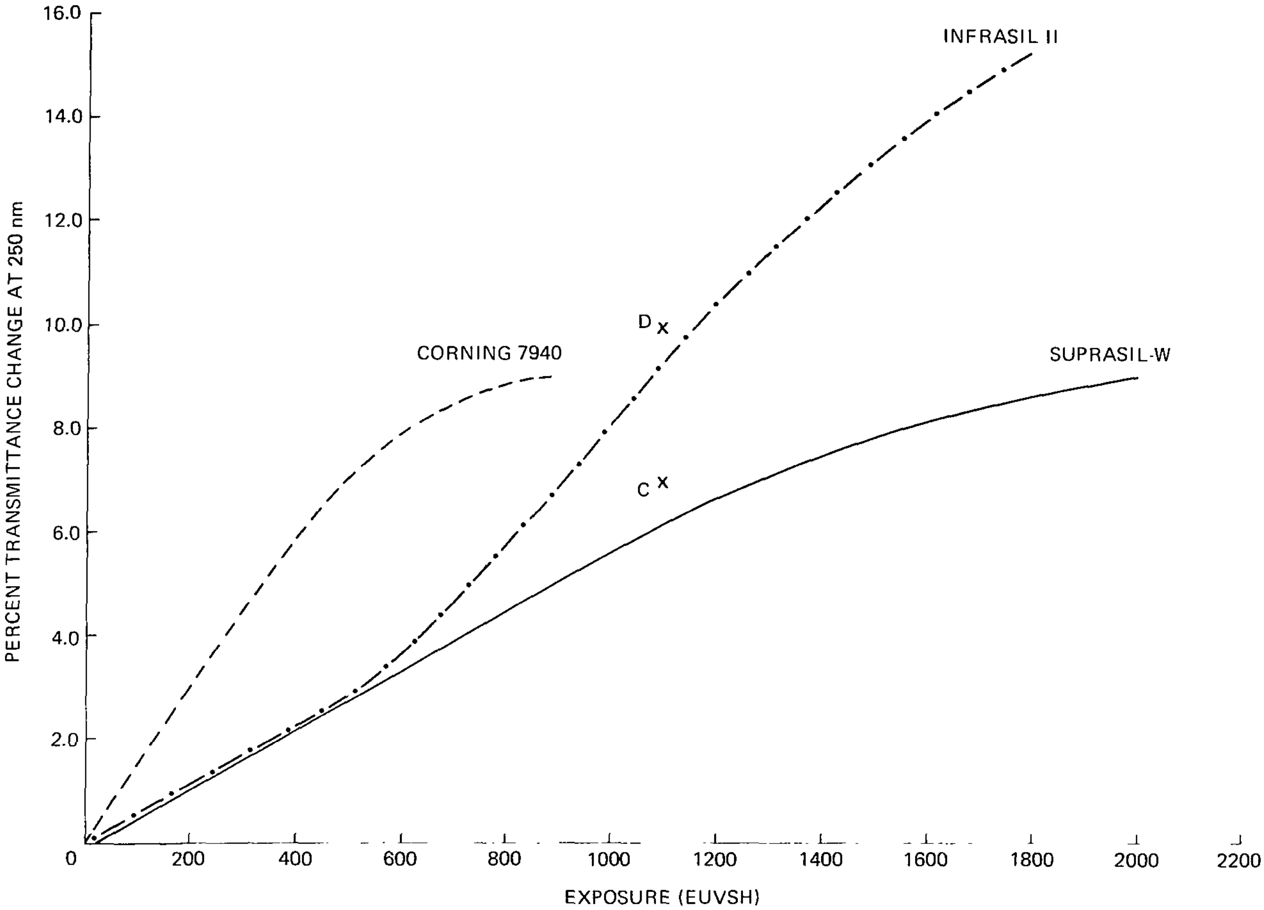

Figure 14—Comparison of the effect of ultraviolet irradiation (at 3.5 UVSC) on the transmittance of fused-silica shielding material.

used to assemble the filters. The results obtained on Filters No. 1 and No. 4 show that, in the selection of ultraviolet and near-ultraviolet interference filters for space applications, care must be taken to ensure that proper thin-film and assembly materials are used.

Goddard Space Flight Center
National Aeronautics and Space Administration
Greenbelt, Maryland, January 4, 1972
604-41-75-01-51

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