RADIATION DAMAGE IN DIAGNOSTIC WINDOWS FOR THE TFTR

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RADIATION DAMAGE IN DIAGNOSTIC WINDOWS FOR THE TFTR*

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Radiation effects in diagnostic window materials are being estimated and additional experimental data on the radiation behavior is being sought. The materials considered thus far are vitreous silica, crystal quartz, and synthetic sapphire.

1. INTRODUCTION

Windows transparent to various wavelengths of light will be required for examination and diagnosis of the plasma in the TFTR. Data for the radiation anticipated at these windows was supplied, and the radiation effects to be anticipated in several window materials were evaluated.

The largest window was to be 0.23 m diameter for observations in the visible region. The greatest effort was devoted to investigating it because of the hazard should such a window fracture. Materials considered for it were vitreous silica and synthetic sapphire. Other windows were to be 51 to 65 mm diameter for observations in other spectral regions. Crystal quartz and sapphire are being considered for them.

2. THE ENERGY SPECTRUM

The neutron and gamma ray spectra were taken from the TFTR conceptual design^[1] where they are given in a multigroup format. To this was added the estimated plasma bremsstrahlung ($w/cm^2 keV$ pulse of 1/2 sec duration) at $0.02 \exp(-E/5)$ where E is the photon energy (keV) and the impurity emission (tungsten) as 25 $w/cm^2 keV$ pulse of 1/2 sec duration over the range 0.1 to 0.5 keV (x-ray energy).^[2]

3. THE RADIATION DAMAGE

The estimates desired were for 400 pulses of neutrons and gamma rays, and for 40,000 pulses of bremsstrahlung and impurity emission x-rays. These pulses were to be of 1/2 sec duration at 5 min intervals. The neutron doses were below most of the available data and the ionization doses were very high.

Initial calculations were for vitreous silica for which more data are available than for other materials, largely because of investigation in our laboratory.^[3] In addition to the published data, the original laboratory files are available, and samples studied for

other purposes over several decades are available for further examination. Since the behavior of other materials relative to vitreous silica has been studied here, these comparisons are available for consideration of the other materials.

The primary consideration in the case of the vitreous silica was the dilatation which, because of shielding and self-absorption, would be non-uniform; and the resultant stresses which would develop. The ion bombardment data and the neutron irradiation data were combined to develop a dilatation (negative) yield function per incident neutron

$$4.411 \times 10^{-21} [0.3257E + 11.47 - 7.589E^{-1} \ln(1.512E + 1)]$$

where here E is the neutron energy. It is estimated that this function has an accuracy of 10% excluding enhanced forward scattering and inelastic scattering at high neutron energies. The effect of ionization is

$$0.028 [1 - \exp(0.762 \times 10^{-6} D^{0.647})]$$

where D is the ionization dose (MegaR).

The problems of optical absorption and luminescence resulting from the radiation will be discussed separately.

4. CALCULATIONS

The multigroup data for neutron and gamma rays were converted into lethargy units (flux in an interval of $\ln E$), plotted and digitized in a suitable number of equispaced intervals. The neutron calculation was carried forward as in earlier publications.^[4] The self-absorption for neutrons is sufficiently small that it was neglected. The total effect was therefore obtained by combining this data with the yield function given above and integrating over lethargy units. For the ionization caused by x-rays and gamma rays, the self absorption is severe; and the local dose must be calculated as a function of depth. The mass absorption coefficient^[5,6] was fitted as follows:

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0.1 to 0.151 keV: $226006 - 1797314E + 42631E^2$
 0.151 to 0.556 keV: $207081 - 1619738E + 5299211E^2 - 8137143E^3 + 480371E^4$
 0.556 to 1.49 keV: $107922 - 334002E + 410186E^2 - 229268E^3 + 48411.41E^4$
 1.49 to 30 keV: $9240E^{-2.8658}$
 30 to 100 keV: $(7.968 - 190.84E^{-1})^{-1}$

The last two parts of this function are not quite right, but are adequate for the present purposes. The deposited energy for energies above 100 keV is so small, it may be neglected. These functions were incorporated into a machine calculation which gave the local energy deposition (and hence the local heating as well) and the dilatation. There is not the space to present the intermediate results.

5. RESULTS FOR VITREOUS SILICA

Irradiation causes a negative dilatation in pure vitreous silica. For the gamma ray flux this is only about 3×10^{-6} at the inner surface with only a 15% attenuation through a 19 mm thickness--negligible. For the neutrons, the value obtained was 1.08×10^{-4} . If a part of the window is completely shielded, differential stresses of 3.79 MPa may result. Such internal stresses themselves are insignificant, but may become important if added to mounting and other stresses imposed on the window. These stresses could be checked readily with simple polarizing equipment.

The effects of the soft x-rays and the impurity emission are serious. The surface energy deposition is formidable, 126 kJ/g pulse. It would cause a temperature rise in excess of 100 deg at the surface; and at the end of the 5 min cycle the temperature of the body would be nearly uniformly 4 deg above the starting temperature were no heat lost by the whole body. At 40,000 pulses, dilatation would be saturated (about 2.8%) to a depth of 1.5 μ m. However, surface crazing has been found by 68.9 MPa in some specimens, a value which would be achieved by a dilatation of 0.23 %. At the surface such dilatation would be achieved in 7 pulses. However, the material appears to yield in small thicknesses without crazing. At 3 μ m this stress would be reached in about 700 pulses. In such thicknesses, crazing is likely. It is evident that cover-slip protection will be required for the window.

6. CONFIRMATORY EVIDENCE

Further examination of crazed vitreous silica specimens indicated that the stress relaxation in vitreous silica is a temporal effect and that the stresses which can be supported varies with the thickness of the layer and the rate at which the stresses are imposed. In thicknesses less than 2 μ m, stresses which have been supported have varied from 172 MPa to 889 MPa. In layers

greater than 2 μ m, crazing has appeared at thicknesses varying from 62 to 145 MPa. It is planned to utilize electron bombardment to further investigate the crazing phenomenon.

Neutron irradiation in ZING is in progress, and is scheduled in RTNS-II, to determine whether enhanced effects are found with high energy neutrons.

Most of the ionization calculations were based on electron bombardment data. A soft x-ray source was calibrated with a Fricke dosimeter and the dilatation yield at small dose was determined as being about half as great as for 0.3 and 0.6 meV or 18 keV electrons.

7. OPTICAL ABSORPTION AND LUMINESCENCE

For the neutron doses of interest, specimens irradiated in CP-5 were examined. Optical absorption became significant below 0.4 μ m. There was also a small peak between 0.55 and 0.69 μ m, which depressed the transmission at the maximum (0.625 μ m) about 10% in 13 mm thicknesses. A blue luminescence is observed on soft x-ray irradiation of neutron irradiated samples. If it does not saturate sooner, it is estimated roughly that the emission would be about 5×10^{-4} lumens/cm². These results were for aged samples. The possibility of a larger prompt effect would have to be investigated.

8. OTHER MATERIALS

1. Crystal quartz: the estimated neutron dose is 6.3×10^{16} . The smallest dose for which we have data is 2.65×10^{17} . The dilatation (positive) is estimated as being between 6×10^{-5} to 1×10^{-4} . The dimensional changes and moduli for the quartz in this range are comparable to those for vitreous silica. It is almost certain that no difficulties would be encountered at half this dose; twice this dose might not be safe. The ionization effects which are found in vitreous silica are not anticipated in crystal quartz, but the material has not, to our knowledge, been tested at the high ionization doses which will be achieved in the TFTR. The assumption is made here that the material will be selected as 100% free from twinning and other defects which would appear in optical, etching, and irradiation inspection.

2. Synthetic sapphire: There are no data for the low neutron doses involved here. However, the dilatation (positive) observed at high dose,^[7] if extrapolated to these doses, would give a quantity less than 10^{-6} , clearly negligible. All samples observed in this laboratory turned moderately dark brown on irradiation,^[8] but this coloration may be impurity dependent. There is a wide variation in the luminescence exhibited on x-irradiation, also apparently associated with impurity. One specimen examined in this laboratory

would have emitted several lumens/cm² at the ionization dose rate of the TFTR if it did not saturate at a lower value; most were very much less luminescent. It is clear that the particular samples to be used as windows would have to be tested. Although no dilatation has been reported for ionization, no data for the doses to be encountered in the TFTR have been found.

9. ACKNOWLEDGMENTS

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The luminescence problem was considered in collaboration with C. Delbecq and P. Yuster of this laboratory.

E. Monahan assisted in determining the x-ray yield for dilatation of vitreous silica.

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