ON THE CHANGE IN THE COLOR AND TRANSPARENCY OF GLASSES WHEN BOMBARDED BY GAMMA RAYS FROM A Co$^{60}$ SOURCE AND IN A NUCLEAR REACTOR

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Glasses of various types are widely used in radiation shielding. The problems involved in the effect of different types of radiation on glasses and the choice of glass with greatest radiation stability become important in this area. The present article deals with these questions. Results of experimental investigations where glasses of different types were subjected to bombardment from a Co$^{60}$ source and to bombardment in a nuclear reactor are discussed. Glasses of different composition, products of several different glassworks in the USSR, were tested. Techniques for enhancing the radiation stability of the glasses are recommended in this article. Those characteristics of glasses which provide a fairly complete picture of the radiation response of the materials, e.g., index of stability, index of saturation, minimum transparency, coefficient of rate of darkening, are introduced.

Glasses darken or color upon exposure to radioactive radiations. The rate of darkening depends on the composition of the glass and the radiation dose; when radiation doses are large, transparency drops rapidly and the color characteristics of the glass are modified. Some data on the stability of industrial glasses to irradiation by $\gamma$ rays may be found in [1].

The present article presents the results of additional investigations of color and transparency changes in glasses upon irradiation using a Co$^{60}$ source in doses up to $10^6$ r, and upon in-pile irradiation with doses reaching $5 \times 10^{10}$ r.

Polished glass specimens 30 mm in diameter and 5±0.1 mm thick were used in the tests. Spectral absorption was determined in a quartz SF-4 spectrophotometer, and integral light transmission was found by using a tricolor VEI colorimeter.

Change in Color of the Glass

Figure 1 shows the curves of the spectral transmittance of various glasses found prior to irradiation and following irradiation with a dose of $10^6$ r from a Co$^{60}$ source. Glass No. 10 from the "Krasnyi luch" works (Fig. 1a), used for the manufacture of extruded items of optical glass; polished (rolled) glass PG from the Dzerzhinskii glass works at Gusev (Fig. 1b); and green glass No. 18 (Fig. 1c) from the "Krasnyi luch" works were used. Both specimens of colorless glass darkened intensely and took on a dark brown coloration.

Figure 2a shows the curves of spectral transmittance prior to and following irradiation of red glasses colored with selenium and cadmium sulfate (selenium ruby glass), Fig. 2b applies to orange cadmium OS-6 glasses, while Fig. 2c refers to blue (cobalt) glasses, No. 17.

Table 1 gives the color characteristics of red glasses of the "copper ruby" type prior to and following irra-

![Fig. 1. Curves of spectral transmittance of glasses: (.....) prior to irradiation; (.....) following irradiation with a dose of $10^6$ r.](image-url)
radiation with a dose of $10^6$ r. We see from the Table that the color characteristics of the glasses suffered negligible change.

**Change in Transparency of the Glass**

Each glass specimen was exposed to various gamma-ray doses ranging from $10^2$ to $10^6$ r, emanating from a Co$^{60}$ source, as well as irradiation in a nuclear reactor, in doses from $10^6$ to $5\times10^6$ r.

Figure 3 shows the variation in the transparency of conventional window glass, OG from the Gorky glassworks (1), polished PG glass from the Gusev works (2), and colorless No. 10 glass, for extruded items, from the "Krasnyi luch" works (3), as a function of radiation dose. The shape of the curves in Fig. 3 demonstrates that soda-lime glasses of compositions generally accepted in industry are stable to gamma-rays for doses of up to $10^4$ r. Only at that dose limit is appreciable darkening of the glass observed. Further irradiation results in rapid darkening; within the $10^6-10^7$ r dose range, the slope of the curve dips, and at $10^7$ r the limit of color saturation sets in. For polished glass, color saturation sets in at lesser doses, at about $10^6$ r.

![Fig. 2. Curves of spectral transmittance of glasses: (-----) prior to irradiation; (-----) after irradiation, dose $10^6$ r.](image)

The integral transparency of window glass irradiated with a maximum dose of $6\times10^6$ r is 7.1%, and for polished glass it is 12.8%, while it is 6.2% for glass No. 10.

Figures 4 to 6 show the curves characterizing the change in transparency of the glasses tested in response to irradiation with γ rays. Inspection of these curves shows clearly that there is an inflection point for each glass corresponding to the gamma dose at which appreciable darkening or an appreciable decrease in the transparency of the glasses begins.

The results of the test show that when a cation of larger ionic radius in the glass is replaced by a cation of smaller ionic radius, the stability of the glass to radiation bombardment is enhanced.

It is plausible to assume that the substitution of the Mg$^{2+}$ ion with its radius of 0.78 Å for the Na$^+$ ion of radius 0.98 Å and the K$^+$ ion of radius 1.33 Å explains the considerable stability to radiation of the rolled glass, compared to No. 10 glass.

**Terminology**

Hitherto, there has existed no unified terminology with respect to the determination of stability of glass to the effects of radioactive radiations. For the stability index ($K_y$) of the glass, it would be feasible to adopt the value of the logarithm of the dose, $D_y$, at which appreciable darkening of the glass sets in, i.e., $K_y = \log D_{sat}$.

A decrease in transparency to visible light of 3-5% will

<table>
<thead>
<tr>
<th>Glass species</th>
<th>Thickness of glass a mm</th>
<th>Wavelength λ mm</th>
<th>Transparency τ, %</th>
<th>Color coordinates x, y</th>
<th>Color saturation, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unglazed No. 13 copper ruby, from &quot;Krasnyi luch&quot;; prior to irradiation</td>
<td>5</td>
<td>620</td>
<td>2.2</td>
<td>0.695</td>
<td>0.305</td>
</tr>
<tr>
<td>following irradiation</td>
<td></td>
<td></td>
<td>0.9</td>
<td>0.700</td>
<td>0.295</td>
</tr>
<tr>
<td>SKSG copper ruby, from the Chernyatinsk works; prior to irradiation</td>
<td>5.1</td>
<td>638</td>
<td>2.6</td>
<td>0.715</td>
<td>0.284</td>
</tr>
<tr>
<td>following irradiation</td>
<td></td>
<td></td>
<td>0.8</td>
<td>0.705</td>
<td>0.285</td>
</tr>
</tbody>
</table>