Radiation-induced Discoloration

“Glass” products typically have amorphous (i.e. non-crystalline) microscopic structures. These products are made from materials that, as they cool form the ‘liquid’ state, become more and more viscous until they become first a soft plastic solid and finally a hard inelastic solid. The basic unit of the glass microscopic structure is the silica tetrahedron.

As such, “glass” is particularly susceptible to radiation-induced discoloration (as are certain transparent and translucent thermoplastic copolymers, e.g. polycarbonate (Lexan) and methylmethacrylate (Acrylic)).

The nature of the changes of the optical properties of glasses under irradiation is varied but usually consists of coloration in the visible-light region and the formation of absorption bands in the infrared and/or ultraviolet regions. The optical density of the glass is almost always increased by irradiation and reaches saturation at exposure of about 10^8 Gray (10^{10} Rad). We refer to this discoloration as “radiation browning” or, simply, “browning”.

The “browning” is not stable, but fades with elevated temperature, time, and exposure to light. The rate of fading of induced color increases as the temperature and/or exposure to light is increased.

The effects of ionizing radiation on glass are discussed in general terms by Levy:

> When glasses are subjected to purely ionizing radiation, such as X-rays or gamma rays, the principal effects will result from purely electronic processes. Specifically, these effects will occur because the electrons are excited sufficiently to leave their normal positions and move through the glass network. In some glasses these ionization processes will be purely transient and after the radiation field is removed the electron distribution will be the same as it was originally, especially if the specimen is of sufficiently high temperature. In other glasses the electron distribution will be permanently altered…The addition or removal of one or more electrons from defect or impurity centers results in the formation of a center that can absorb light, i.e. a color center... The principal interactions of photons with atoms mainly occur in three ways, namely, to produce photoelectrons, Compton electrons, or positron-electron pairs. In passing through the glass network these energetic electrons lose energy by reacting with the less tightly bound electrons, mostly by means of Coulomb forces. If this interaction is strong enough, bound electrons are ejected from their normal orbits with sufficient energy to cause them to move through the network. If this interaction is less strong the bound electrons are still excited but in a way that results in thermal motion of the lattice... electron-deficient regions, or 'holes' as they are usually called, most likely move through the network until they are trapped (by a lattice defect or an impurity). In a similar manner electrons move through the network until they are trapped or recombine with holes... each gamma ray produces one or more electron recoils which in turn produce numerous electrons and holes along its trajectory…Coloring occurs in two well-defined stages, the rapid first stage arising from the coloring of the defects already present in the glass and the second stage resulting from the formation and coloring of defects by the radiation field.