SECTION 11. OPTICAL MEDIA

11.1. GENERAL

The generation of colour centres in optical media by displacement and ionisation effects has been mentioned earlier under the heading "Dielectrics" in the overall survey of radiation-induced responses and is discussed below. In this Section, the windows, lenses and coatings likely to be used in radiation environments are considered. The special subject of optical fibres is dealt within Section 12. The optical path lengths in the media discussed here range from a few micrometres (coatings) to a few centimetres (lenses). Unless otherwise stated, it will be assumed that the pieces of glass or other optical medium considered are in the thickness range 1 mm to 1 cm and that the performance losses of interest are greater than about 20%, such as may be evidenced by visible darkening under irradiation. Translated into other absorption units, the range of concern constitutes values greater than the following:

Absorption:	20%
Absorption :	1 dB
Loss rate:	1 dB mm^{-1} or 10^6 $dB.km^{-1}$
Optical density:	0.1
Absorption coefficient:	0.2303 cm^{-1} or 2303 μm^{-1}
Transmission :	90% (assuming 100% initially)

11.2. COLORATION IN OPTICAL MATERIALS

Transparent solids are normally insulators which also have the property of good light transmission. This is because the forbidden energy gap in these materials is sufficiently large to prevent visible light easily exciting electrons from the conduction to the valence band. However, if radiation or impurities produce defects in the material, visible light may be absorbed because it can now excite electrons into the defects. The intrinsically clear material then becomes coloured. For this reason, optically-absorbing, radiation-induced defects in transparent solids are known as "colour centres".

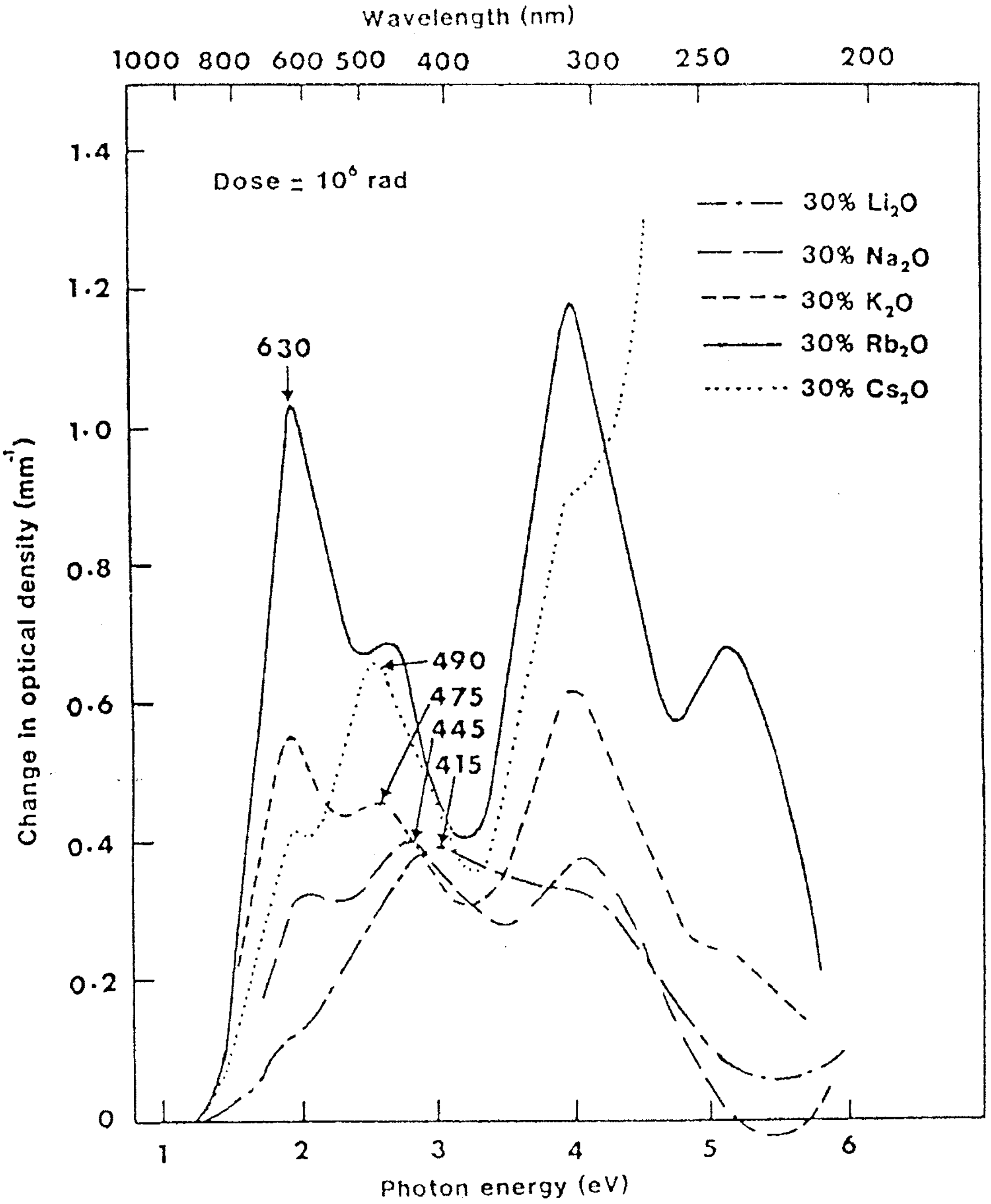
The original work on colour centres concerned alkali halides, which are particularly susceptible to the formation of defects under irradiation. Since then, the field has been extended to cover transparent oxides, such as silica and magnesium oxide and their glassy derivatives. Some colour centres are even used in generating laser beams.

The type of centre most commonly associated with radiation-induced coloration is an ionic vacancy produced by the radiation in the lattice of a crystalline material. However, in many engineering materials, defects exist in the material as processed, and irradiation merely serves to excite electrons into these defects. The latter is the case for most optical glasses, many of which become deeply coloured on exposure to several kilorads of gamma rays or particles. The effect is also turned to good use in some types of dosimeter, which use either the absorption or the associated luminescence as a means of measuring dose.

The nomenclature for simple colour centres is as follows. Anion vacancy centres are known as F centres; these may exist in charged, uncharged or aggregated forms, which bear appropriate subscripts. Cation vacancies are known as V centres, of which there is also a variety.

The effect of composition on radiation-induced absorption in multicomponent glasses is reviewed by Lell et al. (1966) and Stroud et al (1965). Figure 11.1 shows absorption curves from Lell et al. (1966) which demonstrate the variety of absorptions to be expected from optical media and the effect of alkali.

The examples shown are "soft" alkali silicate glasses, but the principles also hold for optical glasses although absorption is often less in the latter. In Figure 11.2 and Table 11(1), Sigel and co-workers at NRL (Evans and Sigel, 1975) have compared the radiation-induced losses in a variety of useful optical glasses. The relevant values at 800 nm vary between approximately the same sensitivity as that of the soft glasses shown in Figure 11.1 (e.g. a loss for lead-flint glass of 1.3 $dB.km.^{-1}$ rad^{-1}) and a sensitivity 300 times lower (zinc crown at 0.04 $dB.km.^{-1}$ rad^{-1}).



Radiation-induced absorption of various alkali silicate glasses about 1 mm thick. All appear to have a specific radiation response at 820 nm of the order 1 $dB.km.^{-1}$ rad^{-1} and exhibit an absorption peak near 630 nm (after Kats and Stevels).

FIGURE 11.1 - RADIATION-INDUCED ABSORPTION OF VARIOUS ALKALI SILICATE GLASSES ABOUT 1 MM THICK

TABLE 11(1) - RADIATION-INDUCED LOSS PER UNIT DOSE IN SELECTED BULK GLASSES AND FIBRES (AFTER EVANS AND SIGEL, 1974/1975)

SOURCE	CODE	TYPE	CORE MATL.	FORM OF GLASS	RESPONSE[a] - $(dB(km\text{-}rad(Si))^{-1}$ λ = .8µm	.9µm	1.05µm
Corning	(CGW)	5010	Pb FLINT	FIBER	5.4	2.5	0.50
Pilkington	(PBL)	HYTRAN	Pb FLINT	FIBER	4.5	1.9	0.50
Galileo	(G)	0001AA	Zn CROWN	FIBER	1.5	0.49	0.25
Schott	(S)	F2	Pb FLINT	BULK	1.3	0.69	0.21
dividing line for values above and below 1 dB/km at λ = 0.8µm.							
NRL		GL2382	BaLa CROWN	BULK	0.65	0.35	0.16
Galileo	(G)	0001AB	Zn(.3% Ce) CROWN	FIBER	0.27	0.0062	0.0026
NRL[b]	-	GL2364	BaLa(1% Ce) CROWN	BULK	0.21	<0.18	---
Owens Corning	(OCF)	X-4147A	Zn CROWN	BULK	0.040	0.020	<0.016
Schott[c]	(S)	F2G12	Pb(1.2% Ce) FLINT	BULK	<0.01	---	---
Schott	(S)	R1	Pb(~1% Ce)	FIBER	0.0031	0.0015	0.0010
Corning	-	-	SiO_2(Ti)	FIBER	$8x10^{-1}$	-	-
Corning	-	-	SiO_2(Ge)	FIBER	$1.4x10^{-2}$	-	-
NRL	-	-	Soda-lime Silicate glass	BULK	$1x10^{-2}$	-	-
NRL	-	-	Suprasil I	BULK	$<1x10^{-5}$	-	-

(a) Except where mentioned, readings made 1 hour after γ-irradiation

(b) 30 min after γ-irradiation

(c) 9 min after γ-irradiation

As regards the visible spectrum, virtually all multicomponent silicate glasses behave like silica in that the radiation-induced absorption in the blue end of the spectrum is much higher than in the red (see Figure 11.2). The radiation-induced loss at 400 nm is usually 10 times higher than at 800 nm. Thus, 20% loss at 800 nm would imply 50% loss at 600 nm and 90% at 400 nm. For these values of loss, samples have a pronounced red-brown or deep yellow colour, depending on the exact spectral shape. A 10-component camera-lens system, irradiated to 10^5 rad, suffered initially similar values of loss, but the coloration faded by about 50% over a few months. Some elements appeared gray rather than brown (Holmes Siedle, unpublished work).

In the design of optical systems tolerant to radiation, the implication is that light in the blue or UV region will be more difficult to handle than red or near IR. Lenses should be tested for radiation-induced loss and for the post-irradiation fading of that loss with time.

"Hardened" optics, pure sapphire and synthetic fused silica have been shown to be extremely insensitive to radiation-induced losses in the visible region (see, for example, Yale, 1968 and Cooley et al., 1963).

11.3. COATINGS

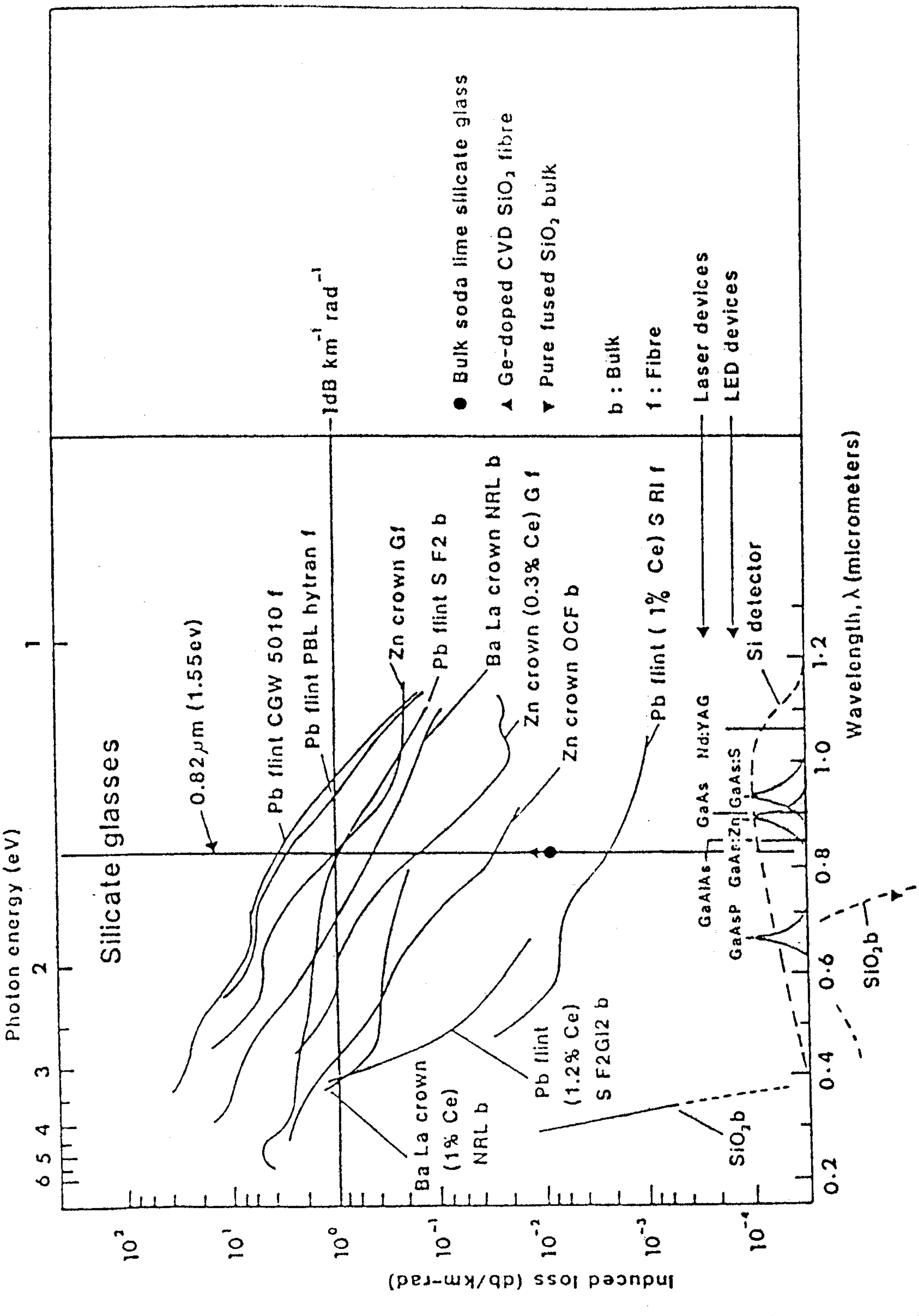
The small optical path length in a typical optical coating (order of micrometres) prevents the development of serious radiation-induced losses in the visible region. The optical properties of films and the effects of radiation on film-forming glasses are reviewed by Wong and Angell (1976). It is unlikely that changes of refractive index, shrinking or swelling will affect optical coating performance under exposure to nuclear and space environments.

11.4. CONCLUSIONS

In the thickness range 1 - 10 mm, many glasses show measurable losses in the dose range 10^4 to 10^6 rads. Thus, optics exposed to space and nuclear radiation may suffer significant losses. Some "hardened" optical glasses are available commercially.

The data given in this section are illustrative only and variation may be expected between batches of material. Samples from batches of material selected for flight use should be tested to verify radiation response.

Since optical media may be subject to "annealing", both temperature and dose rates are important test parameters.



Radiation-induced losses in bulk silicate glasses and fibres one hour after short room-temperature irradiations. Doses ranged from 2 x 10^3 rads (Si) to 5 x 10^5 (Si); at 7 x 10 rads (Si)/s. All curves from Evans and Sigel (1975). Data points from Sigel and Evans (1974), also given on Table 13(1).

FIGURE 11.2 - RADIATION-INDUCED LOSSES IN BULK SILICATE GLASSES AND FIBRES ONE HOUR AFTER SHORT ROOM-TEMPERATURE IRRADIATIONS

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