# EYE EXPOSURE FROM THORIATED OPTICAL GLASS

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## Abstract

During a routine radiation survey of equipment with some optical components the Health Physicist was surprised to find a large reading on an ionization survey instrument. Significant radiation was also observed on a beta-gamma instrument. The source of the radiation was identified as thorium in high quality optical glass. Similar equipment was examined, but not all items produce readings on the survey instruments.

Thorium is added to the glass, in amounts up to 30% by weight, to provide improved optical properties. Similar results may be obtained by using other heavy elements. Thorium is carried as an impurity with some of these elements and the thorium concentration may be greater than 0.05% by weight.

Since the glass is used in an eyepiece, the amount of exposure to the eye should be investigated. The decay chain of thorium contains alpha, beta, and gamma components. Both the alpha and beta components are largely attenuated by the glass. The alpha particles that reach the eye will be absorbed in a thin surface layer, less than 100 microns, the beta components extend over a larger distance, and the gammas will produce almost constant exposure over the entire eye.

The beta-gamma exposure rate was determined by thermoluminescent dosimetry (TLD). The measured exposure rate was 1 mRem/hr averaged for 123 hours exposure at the surface of a lens which contained 18% thorium by weight.

A computer model for the emission of alphas from the glass, the absorption in air and the final absorption in surface layers of the eye provides a technique for examining the amount of exposure at different depths below the surface of the eye. The results of the model will be compared with experimental results from alpha spectroscopy.

Although the alpha particles come from only a small surface layer of the glass, the absorbed dose rate at the surface of the eye may be 50 to 1000 times greater from alpha than from beta-gamma radiation. The size of the lens, and the eye to lens distance determines the number and energy distribution of the alpha particles reaching the eye.

To reduce exposure to the eye, thin non-thoriated glass shields were inserted between the lens and the eye. The results of TLD and alpha counting with and without the shielding showed a complete removal of the alphas.

## Introduction

Our introduction to thoriated glass came as a request to survey some electro-optical equipment with high internal voltages. There was no anticipation of external radiation, but the survey was conducted and 4-5mR of radiation was detected on an ionization type of survey instrument. The eyepiece of the equipment was removed to eliminate some shielding and to bring the survey instrument closer to the expected source of the radiation. However, the radiation level decreased. This process of elimination led to the optical glass as the source of the radiation. Significant radiation was also observed with beta-gamma instrumentation. Identification of the thorium as the source was accomplished by gamma ray spectroscopy.

After the thoriated glass was identified, similar electro-optical equipment was surveyed. Some of the equipment gave positive readings and others were within the natural background. The specifications of the optics were checked, but there were no requirements for thorium.

Thorium is added to glass, up to 30% by weight, to provide improved optical properties. Specifically, glasses with an index of refraction greater than 1.65 and with the product of Abbe constant and index of refraction greater than 70 are often made with thorium. Other heavy elements may be used to obtain similar results. When some of the lanthanide compounds are used, thorium is often contained as an impurity and the thorium concentration may exceed 0.05% by weight.

The use of thorium in optical glass raises few problems unless the glass is an eyepiece. When thorium is in the eyepiece, the eye is exposed to all of the radiation generated by the thorium decay chain - Alpha, betas and gammas - and the associated bremsstrahlung radiation. Initially we considered only the beta-gamma component.

The alpha exposure presented a special problem. The high concentration of thorium gave a high flux of alpha particles. Harvey[1] raised questions on the external radiation hazards of alpha particles. He evaluated plane sources of alpha activity on the skin surface. Witten and Sulzberger[2] investigated the mode of action of thorium on human skin. They found that the thorium was carried into the epidermis. In contrast to the broad surface contamination and the penetration effects, Dean and Langham[3] concentrated on the exposure of the skin to particles of high specific activities. None of these studies provided direct data for evaluating eye exposure from externally originating alpha particles.

In the present study we investigate the exposure of the eye's surface from alpha particles emitted by small quantities of thorium uniformly distributed in glass. A model of the emission and absorption processes of alpha radiation will be developed and the exposure at various layers of the eye's surface will be calculated. Comparison of the theoretical values and some experimental data will be included.

## Thorium Concentrations

Glass manufacturers publish catalogs of glasses. Some of the concentrations approach 30% by weight. The performance characteristics of the optical elements that were in use did not require the thoriated glass. However, it was recognized that some thorium may be included in trace quantities. The uncertainties associated with thorium in glass have led us to set a preliminary level of 0.05% thorium by weight. A survey meter identifies glass with large thorium concentrations, but is ineffective in identification of trace quantities. Gamma ray analysis was not effective on highly thoriated glass to yield the correct percent of thorium. This reflects the lack of secular equilibrium. For trace concentrations, the counting for gamma analysis becomes prohibitive. X-ray flourescence provides a technique for obtaining the thorium concentration. To be accurate, thorium standards in glass matrices similar to the unknown are required.

## Beta-Gamma Components

It was recognized very early that the radiation levels observed with the ionization chamber contained a contribution from the alpha particles. This was most easily observed by placing a thin sheet of paper between the glass and the gauge and noting the reduced instrument readings. In an attempt to obtain a better measure of the beta-gamma exposure rates, thermoluminescent dosimeters (TLD) were placed on two lenses. Total exposure time was 24 hours. These initial measurements included some alpha excitation of the phosphors. A second set of measurements was made with a boro-silicate flat glass 2.8mm thick. The exposure time was 123 hours. The results of these measurements along with the alpha count rates are shown in Table 1. The radiation that can be assigned to beta-gamma is about 1mR/hr.

Table 1. Glass shielding effects
Lens area 6.77cm$^2$

| Lens | Th Concentration | TLD (mR/hr) | | Alpha (counts/min) | |
|---|---|---|---|---|---|
| | | No Shield | Shield | No Shield | Shield |
| 82291 | 18.1 | 5.71 | 0.98 | 1700 | 0 |
| 86200 | 18.4 | 6.45 | 1.39 | 2100 | 0 |

These lenses have a mass of 27.2 grams. The gamma radiation will be proportional to the mass and thorium concentration. The beta component will be absorbed by the glass. Even the most energetic beta will not penetrate more than 2.5mm of the glass.

## Alpha Radiation

The major portion of the survey instrument reading may be explained by alpha radiation. However, the relationship to absorbed dose does not follow from the instrumental reading. In this section, we will derive the number of alpha particles leaving the glass surface, identify the number reaching various depths within the eye, and the associated absorbed dose rates at these levels. Lens to eye distances, and thorium concentration strongly influence these results.

### Range of Alpha.

The range-energy relationships for glass and tissue were calculated for specific energies by a computer program using the procedures outlined by Neufeld, *et al.*[4] The program was checked by comparison with the tables for proton ranges in soft tissue given in the reference. The alpha range in soft tissue was compared with Walsh's[5] results and demonstrates excellent agreement.

The range of alphas in glass is dependent on the glass composition. The chemical composition of a lanthanum glass containing a trace quantity of thorium is shown in Table 2. Small changes in the thorium concentration will have negligible effects on the range of the alpha radiation in the glass.

Table 2. Glass Chemical Composition

Density = 3.64 $g/cm^2$

| Element | Percent | Atoms/$cm^2$ | Atomic No | Atomic Wt |
|---|---|---|---|---|
| La | 35 | $5.51x10^{21}$ | 57 | 138.9 |
| CA | 35.7 | $1.95x10^{22}$ | 20 | 40.08 |
| O | 23.2 | $3.17x10^{22}$ | 8 | 16 |
| As | 3.8 | $1.11x10^{21}$ | 33 | 74.9 |
| Zr | 2.2 | $5.29x10^{20}$ | 40 | 91.2 |
| Th | 0.1 | $9.45x10^{18}$ | 90 | 232.0 |

Even large interchanges between the lanthanum and thorium in percent by weight will have only small changes in the range provided the density remains constant. When the density changes, the range may be calculated as follows:

$$R_N = R\left(\frac{3.64}{P_N}\right)$$

where $P_N$ is the new density and $R_N$ is the new range.

The values for the range-energy for glass, air and tissue are given in Table 3. These values will be used in the subsequent calculations.

Table 3. Alpha - Range-Energy

| Energy (MEV) | Range | | |
|---|---|---|---|
| | Glass (μm) | Air (cm) | Tissue (μm) |
| 1 | .25 | .5 | 4.2 |
| 2 | 1.75 | 1.0 | 9.8 |
| 3 | 5.57 | 1.625 | 16.4 |
| 4 | 10.25 | 2.42 | 25.1 |
| 5 | 15.25 | 3.5 | 35.5 |
| 6 | 20.75 | 4.64 | 47.2 |
| 7 | 27.25 | 5.95 | 61.1 |
| 8 | 34.25 | 7.34 | 75.5 |
| 9 | 41.75 | 8.04 | 91.75 |

Alphas emitted from glass.

For the calculations that follow, the lens is considered as a flat circular glass disc with trace quantities of thorium uniformly distributed throughout. Thorium - 232 is taken in secular equilibrium with all of its daughter products. Although gamma analysis raised doubts that equilibrium exists, the use of this assumption will produce a maximum alpha emission.

Although the total number of alpha particles that leave the surface of the glass is important, we will calculate only those that are directed to an element of the eye's surface. Three distances then become important: $X_a$, the shortest distance between the eye and the lens; $X_g$, the distance the alpha travels in the glass; and the $X_t$, the distance in tissue below the surface of the eye.

Let N(E) be the number of alpha particles emitted per $cm^3$ with an energy E. The number, $dN_c$, from an element of volume and directed toward the selected surface element of the eye, dA, is given by:

$$dN_c = \frac{N(E)dE(2\pi(X_t+X_a)\sin\theta/\cos\theta)((X_t+X_a)/\cos\theta d\theta)\cos\theta dA\cos\theta dX_g}{4\pi((X_t+X_a)/\cos\theta)^2}$$

$$=(N(E)/2)(\sin\theta\cos^2\theta d\theta)dAdX_g dE$$

where θ is the angle between the eye to glass normal and the eye to volume element. This equation may be integrated over the volume of the lens and over the energies to give the total number emitted directed toward the surface element of the eye. All of the alphas emitted will not reach the eye. Absorption of energy begins in the glass, with no alphas originating at depths greater than 40μm every reaching the surface. Additional absorption occurs in the air and finally in the surface layers of the eye. The energy distribution of the initial alphas is known, but as absorption occurs, the energy spectrum changes.

A computer program was written to perform the integrations and calculate the rate and energies of alphas reaching various layers of the eye from different sizes of lenses. This program also calculates the absorbed dose rates at each of the layers.

## Results

Table 4 summarizes the output for the model of a lens 3cm in diameter containing 0.005% thorium.

Table 4. Eye Exposures from 3.0cm

Diameter Lens with 0.005% Thorium

| | 0.1cm Eye to Lens | | 3.0cm Eye to Lens | |
|---|---|---|---|---|
| Eye Penetration $\mu$m | Alpha Count $cm^{-2}hr^{-1}$ | Absorbed dose rate $\mu$ rad $hr^{-1}$ | Alpha Count $cm^{-2}hr^{-1}$ | Absorbed dose rate $\mu$ rad $hr^{-1}$ |
| 0. | 5.52 | 155.62 | .612 | 16.220 |
| 5. | 5.03 | 150.50 | .443 | 11.632 |
| 10. | 4.14 | 124.97 | .320 | 8.480 |
| 15. | 3.25 | 97.44 | .223 | 5.888 |
| 20. | 2.48 | 74.34 | .158 | 4.173 |
| 25. | 1.84 | 55.95 | .114 | 3.006 |
| 30. | 1.32 | 39.97 | .089 | 2.577 |
| 35. | .91 | 27.30 | .069 | 2.144 |
| 40. | .62 | 18.43 | .043 | 1.473 |
| 45. | .41 | 12.29 | .011 | .376 |
| 50. | .29 | 8.46 | 0.0 | 0.0 |
| 55. | .20 | 6.05 | 0.0 | 0.0 |
| 60. | .14 | 4.42 | | |

The 3.0cm eye to lens distance is typical of the operation of some of the systems we investigated. The 0.1cm data are included to obtain some indication of radiation levels at the surface of the glass.

The energy spectrum at the surface of the eye changes with the eye to lens distance. The peak of the energy occurs around 4 Mev and 0.5 Mev for the 0.5cm and 3.0cm distances respectively.

## Discussion

The 1700 alpha counts/min for the lens in Table 1 may be compared with surface count rate in Table 4 by proportions of percentages and correction for area. For the first lens the calculation is as follows:

$$\frac{(1700\ \text{counts/min})\ (.005\%)\ (60\ \text{min/hr})}{(18.1\%)(6.77\text{cm}^2)} = 4.76\ \text{counts hr}^{-1}\text{cm}^{-2}$$

In a similar way, the second lens yields 5.06 counts $\text{hr}^{-1}\text{cm}^{-2}$. Both of these numbers are lower than that given in Table 4. The alpha survey instrument used to measure the count rate has a $1.5\text{mg/cm}^2$ window. This window will be effective in shielding low energy alphas from the detector. The agreement between the measured and computed values is excellent considering the window thickness and the differences in concentration.

About half of all incoming alpha particles are stopped and two-thirds of the energy is deposited in the first 15μm of the surface. This includes the tear layer (7μm) and part of the epithelium. The first mitotic layers occur about 45μm below the surface. Even with the lens at the surface of the eye, only one particle will reach this depth every two hours for each $\text{cm}^2$ of surface.

All of the data was reported for 0.005% thorium. The data may be multiplied by 10 to obtain the results for 0.05% or other appropriate factors to obtain values for other thorium concentrations. Smaller diameter lenses will reduce the alpha flux, but not in a simple relation to area.

In comparison with the alpha absorbed dose, using the data from Table 1, the beta-gamma component is 0.3μ rad when corrected to .005% thorium. At the surface, this represents a factor of 100-1000 less. At the first mitotic cells the two dose rates are about the same.

## Summary

Over 90% of the alpha radiation is absorbed before it reaches the first mitotic layer of the eye. From the data presented, the absorbed dose in the mitotic layer may be calculated and integrated over exposure times. No attempt has been made to relate these values to exposure criteria.

## References

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