GAFCHROMIC® MD-55 RADIOCHROMIC DOSIMETRY FILM FOR HIGH-ENERGY PHOTONS

CONFIGURATION, SPECIFICATIONS AND PERFORMANCE DATA

DESCRIPTION

GAFCHROMIC® MD-55 radiochromic dosimetry film is designed for the measurement of absorbed dose of high-energy photons. In this regard, the response of the film is energy-independent for photons above about 0.2MeV. The structure of GAFCHROMIC® MD-55 radiochromic dosimetry film is shown in Figure MD-1.

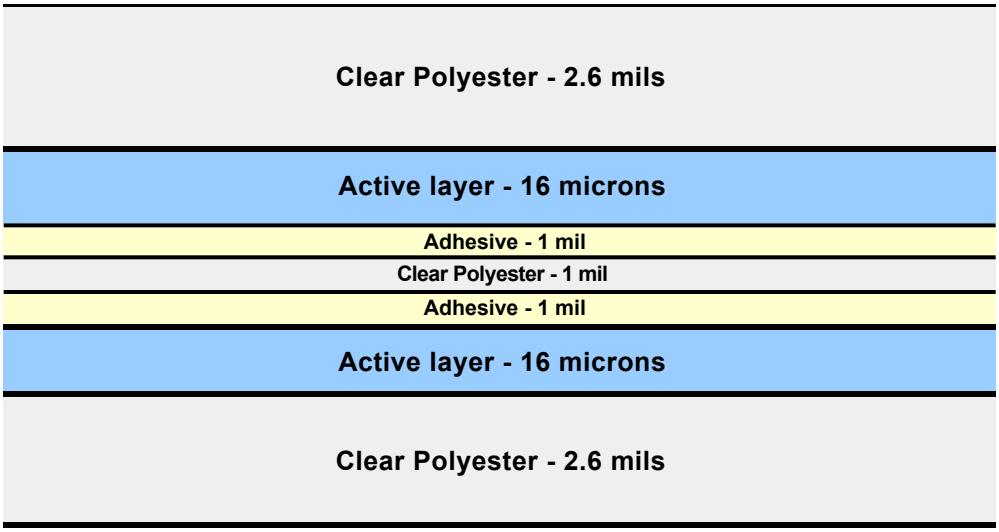

Figure MD-1: Configuration of GAFCHROMIC® MD-55 dosimetry film

An active layer, approximately 16 microns thick, is coated on clear, transparent 2.6 mil (67 microns) polyester. Two pieces of this film are then laminated together with a two-sided adhesive tape composed of the adhesive layers, each approximately 1 mil (25 microns) thick, surrounding a 1 mil thick clear, transparent polyester base. GAFCHROMIC® MD-55 dosimetry film employs the same active component as in GAFCHROMIC® HD-810 and GAFCHROMIC® HS films. In total, GAFCHROMIC® MD-55 has about a 32 micron thickness of active layer. The thickness of the active layer will vary slightly from batch-to-batch in order to provide the product with a reproducible sensitometric response. Details concerning particular batch numbers will be provided upon request.

GAFCHROMIC® MD-55 radiochromic dosimetry film may be measured with transmission densitometers, film scanners or spectrophotometers. When the active component is exposed to radiation, it reacts to form a blue colored polymer with absorption maxima at about 615nm and 675nm. Therefore, the response of GAFCHROMIC® MD-55 dosimetry media is enhanced by measurement with red light. Transmission densitometers for measuring colored films in various color bands within the visible spectrum (e.g. visual, red, green and blue) and are commonly and widely employed in the photographic industry.

However, the Nuclear Associates Radiochromic Densitometer Model 37-443 is especially suited to making spot measurements on GAFCHROMIC® MD-55 dosimetry film since it employs an optimum red LED light source and filter to measure in a narrow band at 660nm. This corresponds very closely to the wavelength of the major peak in the spectrum of the photopolymer. The Howtek MultiRad 460 Film Digitizer, available exclusively through Nuclear Associates, and the Photoelectron Corporporation CCD100 Microdensitometer have similar LED light sources and are therefore optimized for scanning complete 5” x 5” sheets of GAFCHROMIC® MD-55 dosimetry media and films up to at least 8” x 10” in size. The use of red LED

light sources in the scanners or densitometer effectively increases the sensitivity of GAFCHROMIC® MD-55 dosimetry film by 3X relative to black-and-white densitometers, or He-Ne laser scanners.

Low-cost (<$1000) flatbed color scanners are widely available and used in the home and office environments to scan photographic prints and transparencies. When using such devices with GAFCHROMIC® MD-55 films, it is best to scan in transmission mode. These scanners are most commonly color scanners and measure the red, green and blue color components of the film. The response of GAFCHROMIC® MD-55 radiochromic dosimetry film will be maximized by using the scan data from the red color channel.

Some scanning systems and densitometers developed for conventional black and white silver halide medical x-ray film, measure in a wavelength band across virtually the entire visible spectrum. This is not optimum for measuring GAFCHROMIC® MD-55 dosimetry film. However, an enhancement can be obtained by using a deep orange colored filter while scanning or measuring the film. This will effectively restrict the measurement to visible wavelengths greater than about 560nm, where the photopolymer absorbs most strongly. Practically speaking, the response of the film can be improved by 50-75% in this manner, depending on the characteristics of the instrument. Sheets of this orange colored filter are available through Nuclear Associates.

SPECIFICATIONS

The following table lists typical performance data for GAFCHROMIC® MD-55 dosimetry media. The performance of individual batches is available upon request.

Property	GAFCHROMIC® MD-55 Radiochromic Dosimetry Film
Configuration	Two active layers on polyester substrates laminated with adhesive tape
Size	5" x 5" minimum; other sizes upon request
Substrates	260 gauge clear transparent polyester
Active layer thicknesses	Nominally 2 x 16 microns[1]
Laminating tape	100 gauge polyester with double sided adhesive layers approximately 1 mil thick
Sensitometric response	Net density[2] of 0.90 at 25Gy and 1.75 at 50Gy
Energy dependency	<5% difference in net density[2] for 50Gy exposures at 1MeV and 18Mev
Dose fractionation response	<5% difference in net density[2] for a single 40Gy dose and five cumulative 8Gy doses at 30min. intervals
Dose rate response	<5% difference in net density[2] for 10Gy exposures at rates of 3.4Gy/min. and 0.034Gy/min.
Stability in light	<0.005 change in density per 1000lux-day[2,4]
Stability in dark (pre-exposure)	$<0.5 \times 10^{-3}$ density change/day at 23°C $<0.2 \times 10^{-3}$ density change/day under refrigeration
Uniformity, single sheet	<8% sensitometric response difference[3]
Sheet-to-sheet uniformity	<5% sensitometric response difference from mean
Batch-to-batch uniformity	<10% sensitometric response difference from mean
Post exposure density growth	<12% from 1 hr to 1 day after exposure; <4% 1 day to 4 days after exposure

1. Actual thickness may vary slightly from batch-to-batch in order to match sensitivity specification.
2. Measured with Nuclear Associates Radiochromic Densitometer Model 37-443. Net density is the change in density due to the absorbed radiation dose.
3. 2σ.100/density – 49 measurements in a 7x7 grid on a 5" x 5" sheet
4. Cool white fluorescent light

PERFORMANCE DATA

GAFCHROMIC® MD-55 RADIOCHROMIC DOSIMETRY FILM

GAFCHROMIC® MD-55 dosimetry film has been extensively studied and reported on by AAPM Taskgroup 55 (Niroomand-Rad *et al* 1998 Radiochromic Film Dosimetry: Recommendation of AAPM TG55 Med. Phys. **25** 2093-115). The data presented in the following sections include representative information from this source and as well as from ISP's own studies.

SENSITOMETRIC RESPONSE

The information in Figure MD-2 is for Co^{60} exposure of GAFCHROMIC® MD-55 radiochromic dosimetry film batch J1426-MD55. The density measurements were made with a Nuclear Associates Radiochromic Densitometer Model 37-443. Net density is the change in density owing to the exposure dose, i.e. density after exposure minus (base + fog). The response of the GAFCHROMIC® MD-55 dosimetry media as measured by this type of densitometer is essentially linear with dose up to 50Gy.

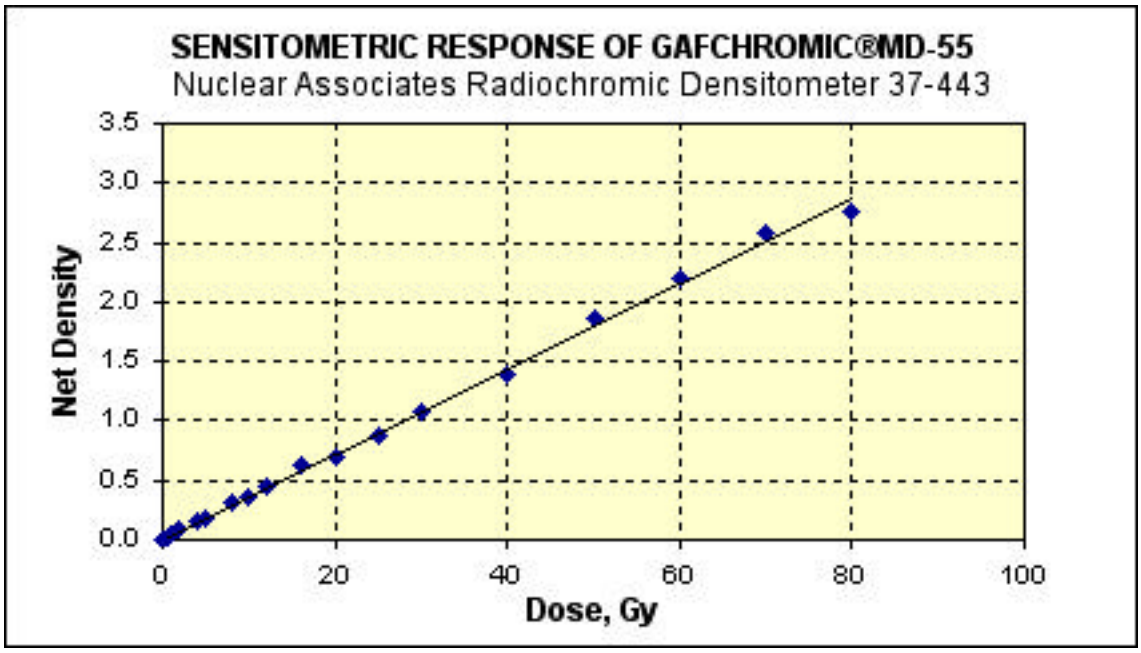

Figure MD-2: Sensitometric response of GAFCHROMIC® MD-55 dosimetry film

DOSE FRACTIONATION

Measurements were made to determine the effect of dose fractionation on the response of GAFCHROMIC® MD-55 Dosimetry Film. The initial densities of two film samples were measured. Each film sample was measured five (5) times. The films were given a total exposure dose of about 40Gy with 120kVp x-rays filtered through 2mm of aluminum. For one sample, the total dose was fractionated into five 8Gy increments each given 30 minutes apart. The other sample received the 40Gy dose in a single exposure lasting a few minutes. The samples were re-measured 24 hours after exposure, each sample again being read in five (5) separate locations. The density differences were calculated by subtracting the densities before exposure from the densities after exposure. Since the total exposures for the two samples were slightly different, the net density values were normalized to correspond to an absorbed dose of 40Gy. The average density changes were calculated and are shown in Table MD-1. Within experimental error, the results for the single and fractionated exposures are indistinguishable and demonstrate that dose fractionation effects are absent.

Dose Fractionation of GAFCHROMIC MD-55 Dosimetry Film - Lot #J1426-MD55			
Total Dose, Gy	Number of Fractions	Number of Measurements	Net Density Change
40	1	15	1.14
40	5 @30minute intervals	15	1.15

Table MD-1: Effect of dose fractionation on the response of GAFCHROMIC® MD-55 dosimetry film, measured with Nuclear Associates Radiochromic Densitometer 37-443

DOSE RATE

The effect of dose rate on the response of GAFCHROMIC® MD-55 dosimetry film was measured and it was found that the film was dose rate independent over dose rates ranging from about 0.034Gy/min to 3.4Gy/min. At each dose rate three samples were exposed to a total dose of about 10Gy. The net density of every sample was measured five (5) times on a Nuclear Associates Radiochromic Densitometer model 37-443. Net density is the change in density due to the absorbed dose. The net density values were normalized to an absorbed dose of 10Gy. The net density data in Table MD-2 are the average values for all fifteen measurements at that dose rate. The net density values differ by only about ±2% from the mean. Such differences are within the experimental error, and thus the results indicate that the film response is dose rate independent.

DOSE RATE DEPENDENCE OF GAFCHROMIC® MD55 Lot# J1426-MD55: 10Gy total dose Nuclear Associates Radiochromic Densitometer 37-443		
DOSE-RATE Gy/min	AVERAGE NET DENSITY	DEVIATION FROM AVERAGE
3.422	0.310	-2.1%
0.334	0.320	1.1%
0.034	0.320	1.1%
AVERAGE ALL	0.317	

Table MD-2: Effect of dose rate on the response of GAFCHROMIC® MD-55 dosimetry film

POST-EXPOSURE DENSITY GROWTH

The active component in GAFCHROMIC® dosimetry films is a radiation sensitive monomer. Upon exposure to radiation, the active component polymerizes to form a dye polymer. The polymerization has been investigated by McLaughlin, et al (ACS Symposium Series, "Irradiation of Polymers, Fundamentals and Technological Applications", Chapter 11, American Chemical Society 1996). This work showed that after flash photolysis the reaction has an incubation period of at least 1 microsecond. After pulsed electron beam radiolysis, the polymerization proceeds with first order kinetics and a rate constant of about 10^3 sec^{-1} In the first minutes after exposure, the post-exposure density growth effect manifests itself as a significant increase in optical absorption. This corresponds to an increasing concentration of polymer within the active layer. However, the rate of change of absorption diminishes rapidly with time. Thus the optical absorption asymptotes to a practically constant value about 2 days after exposure.

If measurements are to be made within a few hours of the exposure, a practical and effective technique to eliminate error due to the effects of post-exposure density growth is to make the density or optical absorption measurements at a consistent time after exposure. Alternatively, errors caused by mistiming of the measurements can be practically eliminated if such measurements are delayed until 24hours, or more, after the exposure.

The data in Figures MD-3 and MD-4 show the post-exposure density growth of GAFCHROMIC® MD-55 radiochromic dosimetry film. In Figure MD-3 the densities of several film samples exposed to different absorbed doses of x-rays are plotted versus the time after exposure. This reveals that the rate of change of density decreases continuously and rapidly with time after exposure, becoming very slow within about 24 hours.

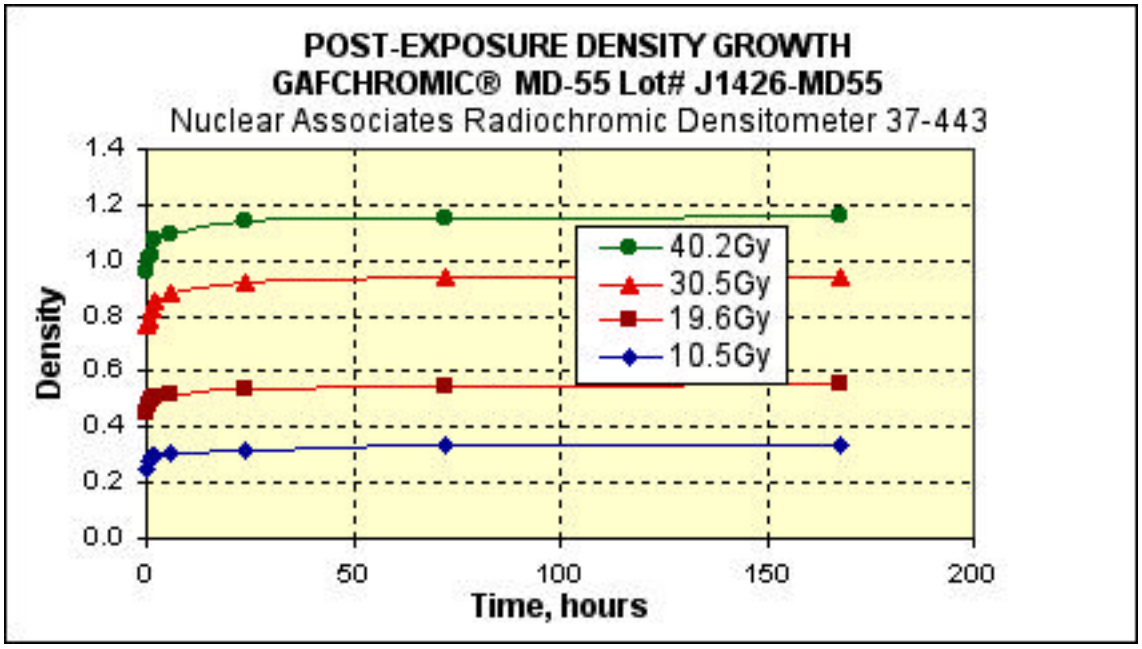

Figure MD-3: Post-exposure density growth of GAFCHROMIC® MD-55 dosimetry film

In Figure MD-4, the density data for each individual exposure has been normalized to the value of the density at 24 hours after exposure. This figure reveals that post-exposure density growth, relative to the density at 24 hours, is essentially independent of exposure dose. The density changes about 10% in the period between 1 hour after exposure and 24 hours after exposure, but the rate diminishes and the density changes by less than 2% over the next 96 hours.

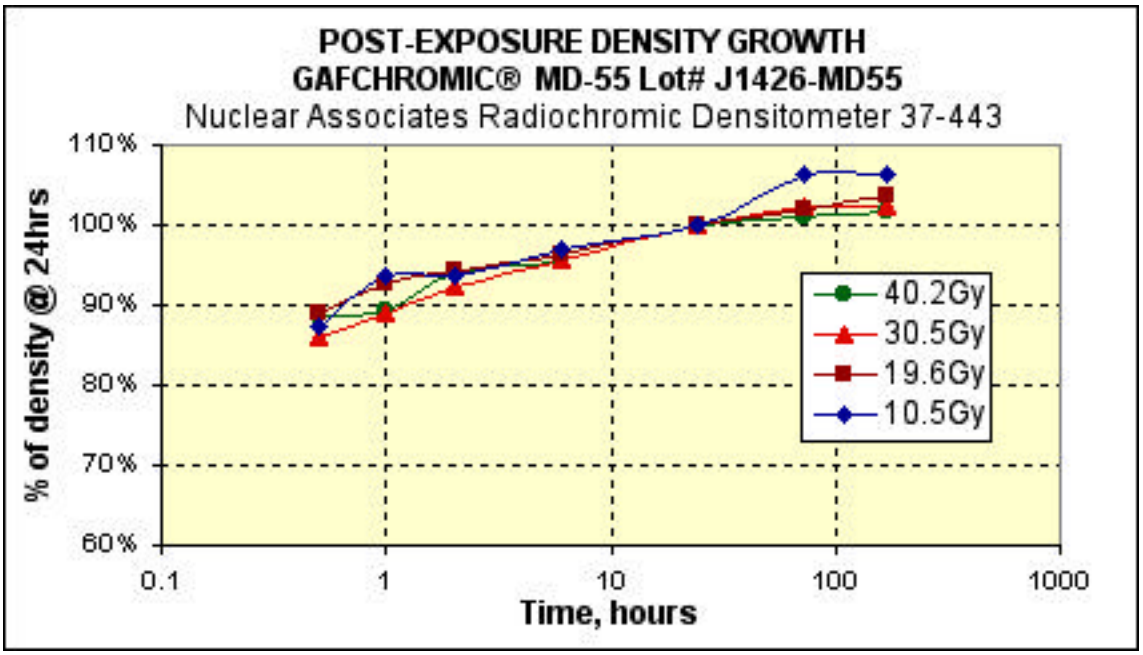

Figure MD-4: Normalized post-exposure density growth of GAFCHROMIC® MD-55 dosimetry film, measured with Nuclear Associates Radiochromic Densitometer 37-443

UNIFORMITY IN THE CROSS-WEB AND DOWN-WEB COATING DIRECTIONS

Four 5" x 5" sheets of GAFCHROMIC® MD-55 dosimetry film were stacked on top of one another and exposed to an absorbed dose of about 40Gy at the University of Wisconsin. The field size of the beam was approximately 6" square with a flatness of about 2%. The film sheets were marked to indicate the directions orthogonal (cross-web) and parallel (down-web) to the coating direction. Prior to the exposures the optical densities of each sheet had been measured in forty-nine locations arranged in a regularly spaced 7x7 array. The densitometer was a Nuclear Associates Radiochromic Densitometer, Model 37-443.

Seven days after exposure the densities of all samples were re-measured (49 locations per sheet) and the change in the density at each of the measurement points was calculated. Then, for each sheet, the average value and standard deviation was calculated in the down-web and cross-web directions, as well as an overall average and standard deviation for that sheet. Finally the cross-web, down-web and sheet uniformities were calculated as defined by two times the standard deviation divided by the average, expressed as a percentage. With uniformity expressed in this manner, ninety-six percent (96%) of the measurements on a uniformly exposed sheet would fall within $\pm 2\sigma$ of the average.

The results in Table MD-3 show that the cross-web uniformity, calculated as the average of all measurement sets, was 6.6% and values of the twenty-eight sets of measurements ranged from 1.9% to 11.0%. Similarly the down-web uniformity is 4.1% with the individual values ranging from 1.8% to 6.4%. The overall uniformity of the four sheets, cross-web and down-web combined, was 6.6% with the values for individual sheets ranging from 3.7% to 8.9%.

UNIFORMITY OF GAFCHROMIC® MD-55 DOSIMETRY FILM - Lot# J1426-MD55			
Direction	Number of measurements	Uniformity (2x std. dev./average)	Range of values
cross-web	28 x 7	6.6%	1.9% - 11.0%
down-web	28 x 7	4.1%	1.8% - 6.4%
whole sheet	4 x 49	6.6%	3.7% - 8.9%

Table MD-3: Uniformity of GAFCHROMIC® MD-55 dosimetry film, exposed to 25Gy and measured with Nuclear Associates Radiochromic Densitometer 37-443

WHITE LIGHT SENSITIVITY

Numerous tests and observations have clearly established that while the active component in GAFCHROMIC® dosimetry films is not particularly sensitive to visible light, it is comparatively more sensitive to short wavelength light than to long wavelength light. The interior environment in buildings is predominantly illuminated with incandescent or cool white fluorescent light bulbs. The latter produce a higher proportion of blue light and the former a higher proportion of red light. Therefore, in measuring the white light sensitivity of GAFCHROMIC® MD-55 dosimetry film, tests were performed in the more demanding condition by exposing the film to the light from cool white fluorescent bulbs.

Offices and laboratories are commonly illuminated by cool white fluorescent light bulbs. The intensity of the illumination on working surfaces such as desktops and laboratory benches was measured in a representative number of offices and laboratories. It was found that the light intensity was in the range from about 600lux to 1000lux. Therefore, for the purpose of the evaluation of white light sensitivity of GAFCHROMIC® dosimetry films it was assumed that "standard" indoor illumination intensity is 1000lux.

A light table comprised of cool white fluorescent light bulbs illuminating an opal glass viewing surface was used as a test fixture. The intensity of light at the surface of the glass was measured at about 2900 lux. Samples of GAFCHROMIC® MD-55 dosimetry film about 1"x1" in size were cut and the Status Red densities of the samples were measured with an X-Rite 310T densitometer. The samples were then placed on the surface of the light table and covered with a black sheet to shield them from room light. The temperature of the samples was 23±2°C during the test period. At various intervals up to 26 days the densities of the samples were re-measured. The density change values were calculated and normalized to a light intensity of 1000lux and plotted against the exposure in lux-days. An exposure of 1000lux-days represents the quantity of visible light that a film sample would receive were it to be exposed to the illumination in the "standard" indoor environment for 24 hours.

The data have been plotted in Figure MD-5. The trend of the data points suggests that the rate of change of density diminishes with exposure time. This behavior has been consistently seen in previous measurements of the white light sensitivity of GAFCHROMIC® dosimetry films. However, for simplification, it has been assumed that the change in density is linear with time. A linear fit of the data shows that the trendline has a slope of 0.00086 density units per 1000lux-days of exposure, i.e. the amount of exposure if the "standard" interior illumination of 1000lux intensity was applied for an entire 24-hour period. This low white light sensitivity indicates that GAFCHROMIC® MD-55 dosimetry film can be handled in normal room light for at least several hours without noticeable effects. However, it also suggests that the film should not be left exposed to room light indefinitely, but rather should be kept in the dark when it is not being handled.

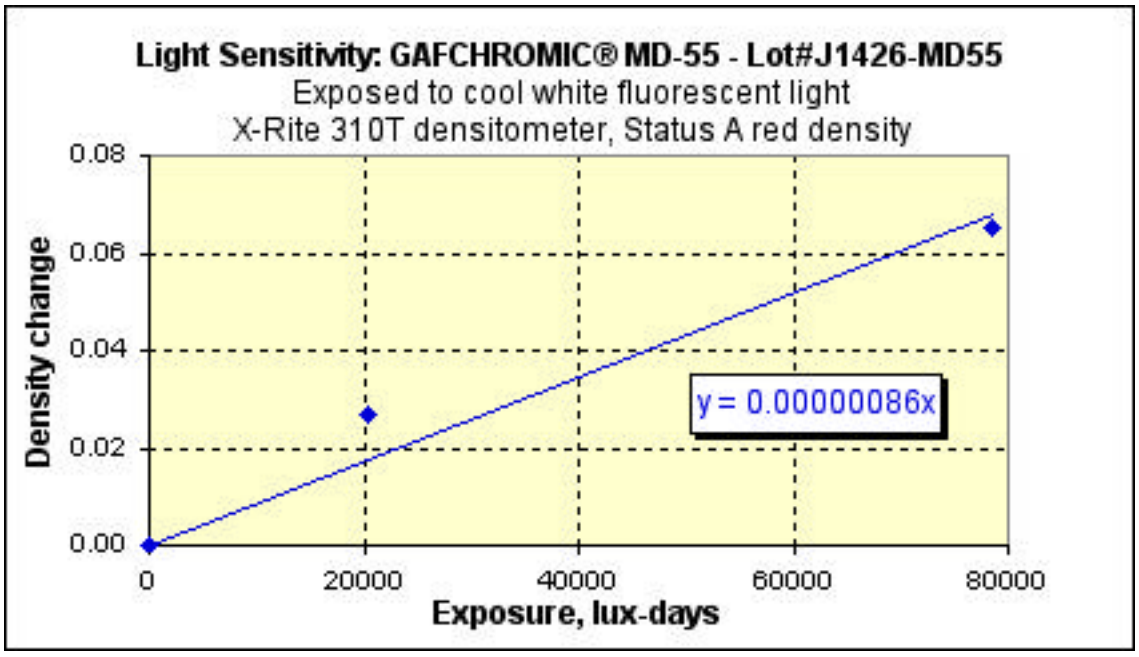

Figure MD-5: White light sensitivity of GAFCHROMIC® MD-55 dosimetry film