GAFCHROMIC® HD-810 Radiochromic Dosimetry Film
Configuration, Specifications and Performance Data

Description

GAFCHROMIC HD-810 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 approximately 0.2 MeV.

The structure of GAFCHROMIC HD-810 radiochromic film is shown in Figure HD-1.

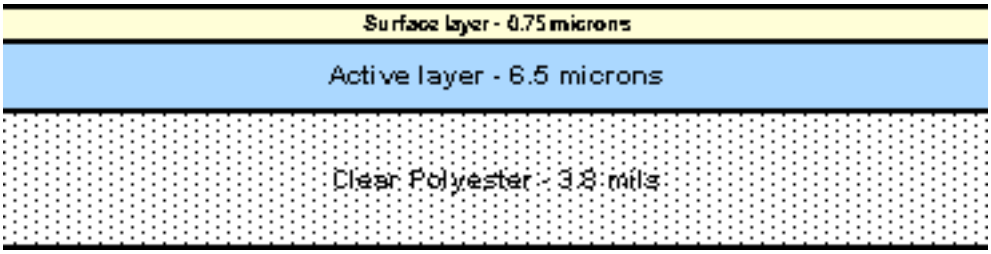

Figure HD-1: Configuration of GAFCHROMIC® HD-810 dosimetry film

The active layer, approximately 6.5 microns thick, is coated on clear, transparent 3.8 mil (~ 97 microns) polyester. There is a gelatin surface layer approximately 0.75 microns thick. The thickness of the active layer may vary slightly from batch-to-batch.

GAFCHROMIC HD-810 radiochromic dosimetry film may be measured with transmission densitometers, film scanners or spectrophotometers. When the active component in GAFCHROMIC HD-810 film is exposed to radiation, it reacts to form a blue colored polymer with absorption maxima at approximately 615 nm and 675 nm. Therefore, the response of the dosimetry film media is enhanced by measurement with red light. In using a spectrophotometer the greatest response is obtained by scanning the film and using the peak absorbances. Most densitometers measure over a band of wavelengths and transmission densitometers for measuring colored films measure over various narrow color bands within the visible spectrum, e.g. visual, red, green and blue. Such densitometers are commonly and widely employed in the photographic industry.

The EPSON Expression 10000 XL PHOTO 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 HD-810 films, it is best to scan in transmission mode. These scanners are color scanners and measure the red, green and blue color components of the film. The response of HD-810 dosimetry film is maximized via using the scan data from the red color channel. The VIDAR DosimetryPRO Advantage (Red) medical film scanner has red LED light sources, and it can be used also. The use of the red LED light sources in the scanners or densitometer effectively increases the sensitivity of GAFCHROMIC HD-810 dosimetry film by approximately 3X relative to black-and-white densitometers, or He-Ne laser scanners.

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 HD-810 dosimetry film. However, an enhancement can be obtained by using a deep orange colored filter while scanning or measuring the film, restricting the measurement to visible wavelengths greater than approximately 560 nm, 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.

Specifications

The following table lists typical performance data for GAFCHROMIC HD-810 radiochromic dosimetry media.

Property	GAFCHROMIC® HD-810 Film
Configuration	Active layer and surface layer on polyester substrate
Size	8" x 10" minimum; other sizes upon request
Substrates	380 gauge clear transparent polyester
Active layer thicknesses	Nominally 6.5 microns[1]
Surface layer	Nominally 0.75 microns
Sensitometric response	Net density[2] of 0.30 at 100 Gy and 1.15 at 500 Gy
Energy dependency	<5% difference in net density[2] for 250 Gy exposures at 1 MeV and 18 Mev
Dose fractionation response	<5% difference in net density[2] for a single 40 Gy dose and five cumulative 8 Gy doses at 30 min. intervals
Dose rate response	<5% difference in net density[2] for 10 Gy exposures at rates of 3.4 Gy/min. and 0.034 Gy/min.
Stability in light	<0.005 change in density per 1000 lux-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 refrigerated
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. Visual transmission density measured with X-Rite 310T densitometer. Net density is the change in density due to the absorbed radiation dose.
3. 2s.100/density - 49 measurements in a 7x7 grid on a 5" x 5" sheet
4. Cool white fluorescent light

Performance Data

Sensitometric Response

The information in Figure HD-2 is for Co^{60} exposure of GAFCHROMIC HD-810 radiochromic dosimetry film batch H1032H810. 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 HD-810 dosimetry media is essentially linear with dose up to 250Gy when measured with this type of densitometer.

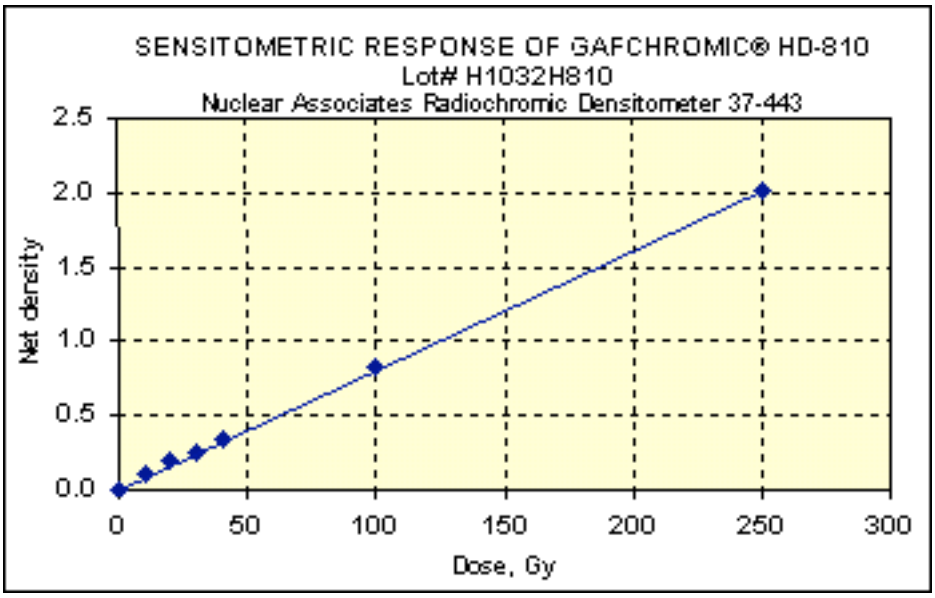

Figure HD-2: Sensitometric response of GAFCHROMIC HD-810 dosimetry film

Energy Dependence

McLaughlin et al (Figure 14 in Nuclear Instruments and Methods in Physics Research A302 (1991) 165-176) showed that the response of GAFCHROMIC HD-810 is independent of energy when exposed with Co^{60} and 10 MeV electrons. Muench et al (Medical Physics, 18, 769-775 (1994)) have shown that the response of GAFCHROMIC HD-810 decreases by approximately 30% when the effective photon energy decreases from 1710 keV (4 MV x-rays) to 28 keV (60 kVp x-rays, 2 mm Al filtration).

Dose Fractionation

Chu et al (Radiation Physics and Chemistry, 35, 767-773 (1990)) studied dose fractionation of GAFCHROMIC HD-810 dosimetry film. Two exposures were made. In one, the dose was divided into five fractions at twelve-minute intervals and in the

other the dose was delivered in a single exposure. The absorbance values of the fractionated and unfractionated samples were within 1%, indicating that a fractionation effect was absent. A similar result was obtained when the irradiation was interrupted by 24 hours.

Further measurements were made of the effect of dose fractionation on the response of GAFCHROMIC HD-810. The initial densities of five film samples were measured on a Nuclear Associates Radiochromic Densitometer 37-443. Each film sample was measured 5 times. The films were given a total exposure dose of approximately 100 Gy (120 kVp x-rays, 2mm aluminum filtration). For three samples, the total dose was fractionated into five 20 Gy increments each given 30 minutes apart. The other two samples received the 100 Gy dose in a single exposure. The samples were re-measured 24 hours after exposure, each sample again being read in 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 100 Gy. The average density changes were calculated and are shown in Table HD-1. The results for the single and fractionated exposures are indistinguishable and demonstrate that dose fractionation effects are absent.

Dose Fractionation of GAFCHROMIC HD-810 Dosimetry Film Lot #H1032H810			
Total Dose, Gy	Number of Dose Fractions	Number of Measurements	Net Density Change
100	1	10	0.694
100	5 – at 30 minute intervals	15	0.693

Table HD-1: Effect of dose fractionation on the response of GAFCHROMIC HD-810 film, measured with Nuclear Associates Radiochromic Densitometer 37-443

Dose Rate

Saylor et al, Radiation Physics and Chemistry, 31, 529-536, (1988) reported that there were no measurable dose rate effects from exposures of to radiation from a Co^{60} source at rates between approximately 0.02 Gy/min and 200 Gy per minute The film used in this study was identical to the film in GAFCHROMIC HD-810 dosimetry medium.

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 approximately 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 approximately 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 HD-3 and HD-4 show the post-exposure density growth of GAFCHROMIC HD-810 radiochromic dosimetry film. In Figure HD-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 considerably slow within approximately 24 hours.

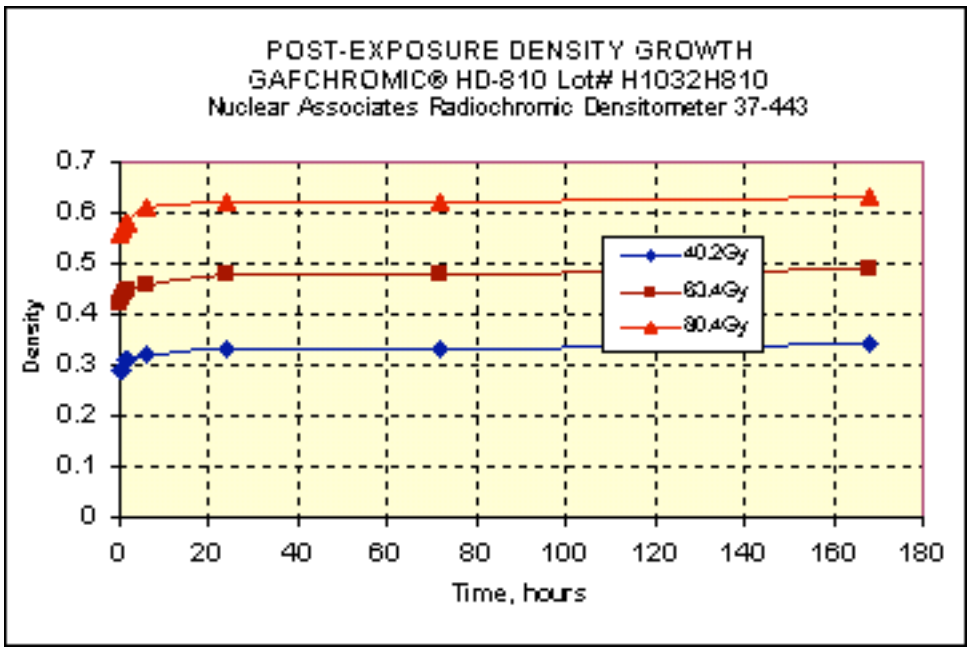

Figure HD-3: Post-exposure density growth of GAFCHROMIC HD-810 film

In Figure HD-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 approximately 8% 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.

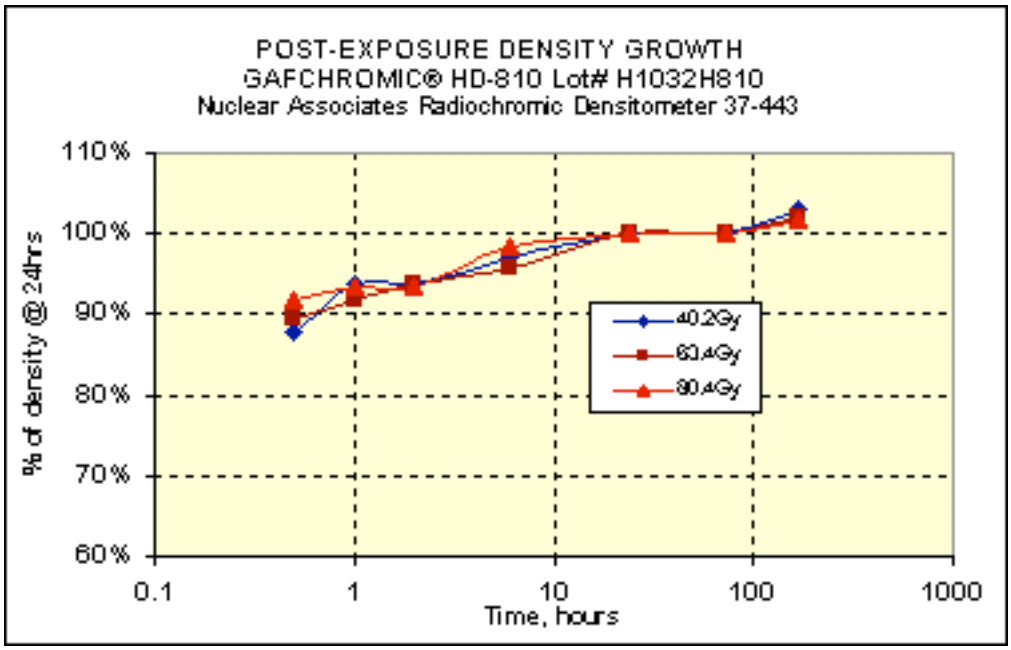

Figure HD-4: Normalized post-exposure density growth of GAFCHROMIC HD-810 film, measured with Nuclear Associates Radiochromic Densitometer 37-443

Uniformity In The Cross-Web And Down-Web Coating Directions

Four 5" x 5" sheets of GAFCHROMIC HD-810 dosimetry film were stacked on top of one another and exposed to an absorbed dose of approximately 40 Gy at the University of Wisconsin. The field size of the beam was approximately 6" square with a flatness of approximately 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.

The results in Table HD-2 show that the cross-web uniformity, calculated as the average of all measurement sets, was 2.6% and values of the fourteen sets of measurements ranged from 1.6% to 4.5%. Similarly the down-web uniformity is 2.6% with the individual values ranging from 0.8% to 4.1%. The overall uniformity of the two sheets, cross-web and down-web combined was 3.2% with the values for individual sheets ranging from 3.0% to 3.4%.

UNIFORMITY OF GAFCHROMIC HD-810 DOSIMETRY FILM Lot# H1032H810			
Direction	Number of measurements	Uniformity (2X std. dev./average)	Range of values
cross-web	14 x 7	2.6%	1.6% - 4.5%
down-web	14 x 7	2.6%	0.8% - 4.1%
whole sheet	2 x 49	3.2%	3.0% - 3.4%

Table HD-2: Uniformity of GAFCHROMIC HD-810 dosimetry film, exposed to 25 Gy 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 the film in GAFCHROMIC HD-810 dosimetry media, 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 approximately 600 lux to 1000 lux. Therefore, for the purpose of the evaluation of white light sensitivity of GAFCHROMIC dosimetry films it was assumed that "standard" indoor illumination intensity is 1000 lux.

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 approximately 2900 lux. Samples of GAFCHROMIC HD-810 dosimetry film approximately 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 1000 lux and plotted against the exposure in lux-days. An exposure of 1000 lux-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.

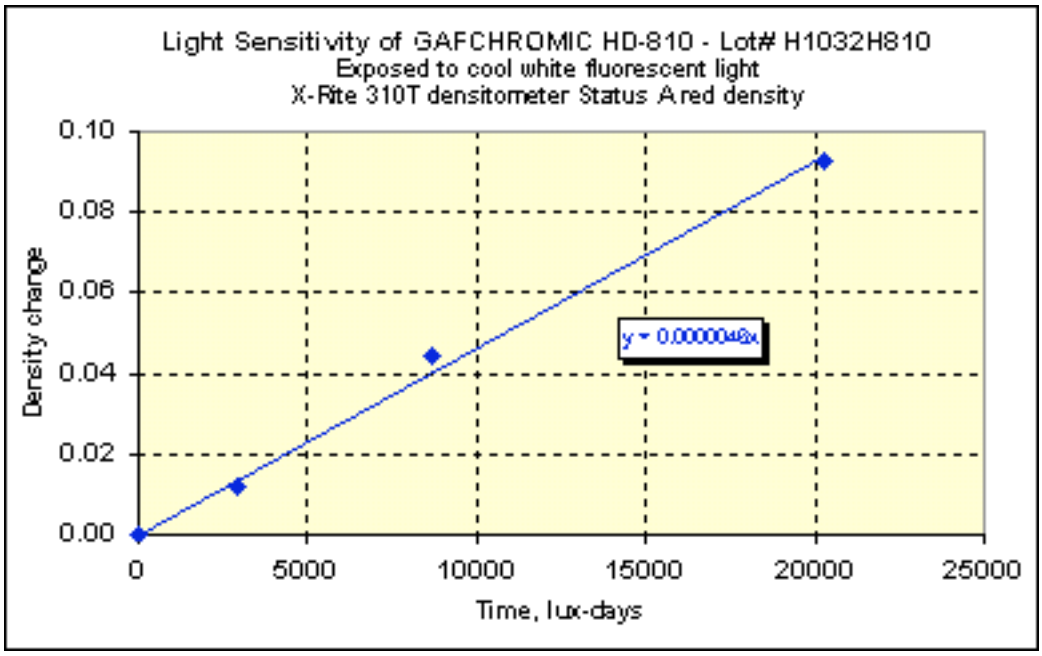

Figure HD-5: White light sensitivity of GAFCHROMIC HD-810 dosimetry film

The data have been plotted in Figure HD-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 0.0046 density units per 1000 lux-days of exposure, i.e. the amount of exposure if the "standard" interior illumination of 1000 lux intensity was applied for an entire 24-hour period. This low white light sensitivity indicates that GAFCHROMIC HD-810 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.