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Recent Fluoro-Glass Dosimeter Development

Portable digital fluoro-glass dosimeter

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THE FLUORO-GLASS dosimeter was first invented by J.H. Schulman, et al. of the Naval Research Laboratory, U.S.A. It was based on Radio-photoluminescence (abbreviated RPL) of silver-activated phosphate glass. Later on, it was improved by Yokota and other researchers in regard to many points; namely, high sensitivity, low photon energy dependence and low background luminescence (predose).

Those days, a fluoro-glass dosimeter was highlighted for personnel monitoring. With the spread of the fluoro-glass dosimeter, however, complicated glass handling and the limit in low exposure measurement became vital restrictions. Simultaneously, personnel monitoring became more strict, requiring 10 mR or less sensitivity.

Glass dosimeter system, however, has many unique merits, compared to other solid-state dosimeters. They are, for example, uniform sensitivity between glasses, repeatability and integrality during intermittent monitoring and reading, low photon energy dependence and extremely low fading during long term monitoring. A dosimeter, FGD-6, has been applied to low dose region, down to 10 mR.

A new dosimeter FGDP-7 has just been developed for the dose region between 0.2 R to 2,000 R. It is suitable for personnel emergency dosimetry, radiotherapy, field monitoring and civil defense purposes. Furthermore, it is portable with digital display.

Radio-Photoluminescence (RPL) and Build-up of Silver-Activated Phosphate Glass

When silver-ion containing (silver-activated) phosphate glass is exposed to ionizing radiation, stable luminescent centers are formed in the glass. When the glass is then excited by ultraviolet rays, the centers emit orange luminescence with a peak wavelength of from 500 to 750 nm. The phenomenon is called RPL. The luminescence intensity is proportional to both the prior irradiation dose and the ultraviolet-ray intensity.

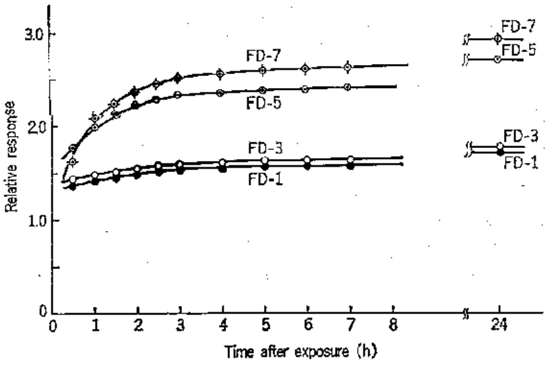

FIG. 1. Dosimeter glass build-up characteristics at room temperature

The centers are stable against ultraviolet irradiation. Furthermore, the population of the centers is proportional to accumulated dose of the glass. This enables intermittent exposure and reading, total dose measurement and repeated readings.

Positive holes and electrons formed by ionizing radiation rearrange or react with each other or with ions in glass to form stable luminescent centers. The reaction and stabilization rates depend upon temperature and glass composition; luminescence intensity builds up with time after exposure to reach final value. **Figure 1** shows build-up characteristics for several dosimeter glasses. At 100°C, build-up completes in 10 minutes. The stable centers are presumed to be Ag°, Ag°-Ag° pairs and Ag^{++} ions.

Predose and Sensitivity

Luminescence intensity for a dosimeter glass before irradiation to ionizing radiation behaves as background noise for dosimetry. The dose equivalent of the background luminescence is called predose. Predose limits the measurable lowest dose (**Table 1**). Although predose causes have not been fully clarified, careful examination and adjustment of raw material prepara-

Table 1. Dosimeter Glass Predose and Sensitivity

Glass Name	Predose (mR)	Sensitivity	Silver Concentration (%)
FD-1	230	1.0	3.677
FD-3	220	1.05	3.267
FD-5	150	1.51	0.520
FD-7	140	1.65	0.173

tion, melting, casting and annealing conditions and glass composition give stable production yield, low predose variation between melting lots and uniform sensitivity. Low silver concentration increases sensitivity and decreases predose and energy dependence. Low silver concentration, however, slightly increases build-up time (**Fig. 1**).

Linear Dose vs. Reading Relations

In Toshiba Fluoro-Glass Dosimeter, FGD-6 (**Fig. 2**), the lowest measurable dose is equal to 10% of glass predose. Standard-exposure by Co^{60} γ rays of FD-3 and FD-7 glasses and FGD-6 dosimeter gave the results shown in **Fig. 3**. The dose-response relations were linear with standard deviations of 1.5% or less. The linearity extended up to 10 R by intermittent exposure.

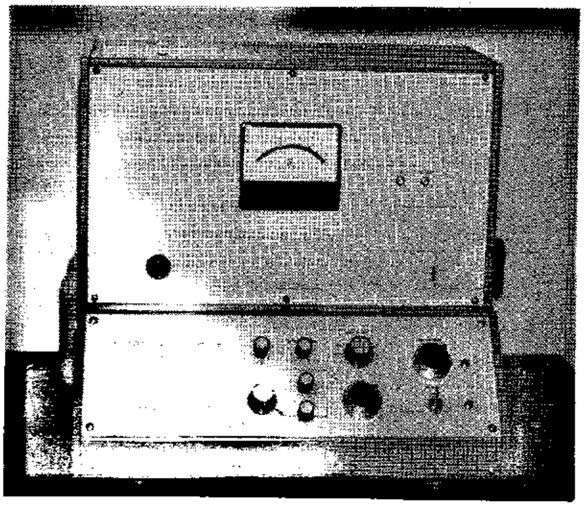

Fig. 2. Toshiba fluoro-glass dosimeter, Model FGD-6

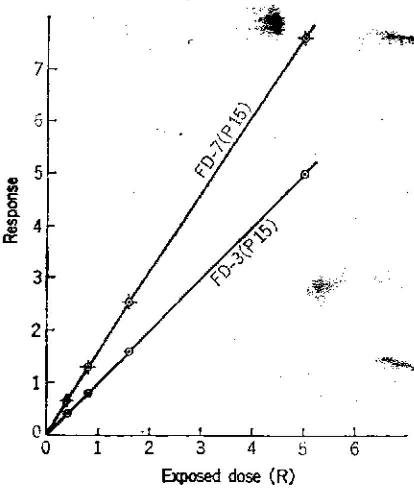

Fig. 3. Dose-response relations of FD-3, FD-7 glasses

Portable Digital Fluoro-Glass Dosimeter (FGDP-7)

This newly developed dosimeter, Model FGDP-7, has the following features, in contrast to a conventional precision measurement use dosimeter, Model FGD-6.

(1) This dosimeter is built up in light-weight and small-size formation, enabling use as a portable unit (capable of being battery operated, as well).

(2) Measurement is completed by pushing a switch and then measured value is indicated in a radiation dose unit (Röntgen).

(3) A xenon flush lamp is used as an ultraviolet-ray exciting light source and fluorescence light emitted from the glass in a pulsation mode is measured.

(4) Measurement range is from 0.2 to 3,000 R and is suitable for measurement of relatively high radiation level, wherein its measurement accuracy and reproducibility become amazingly good.

Pulse Emission Measurement Method

In this meter, a xenon flash lamp that flickers in the same way as a stroboscope used in photography is used for ultraviolet-ray excitation light source, replacing conventional mercury lamp's continuous lighting method. As indicated in **Fig. 5**, ultraviolet rays emitted in a pulsation mode are emitted on a measurement object glass element and then radio-photoluminescence (RPL) coming from the glass in a secondary fashion is measured by photomultiplier (or by a photo-diode) and integration circuit, in combination, for radiation dose measurement.

The intensity of radio-photoluminescence coming from the dosimeter glass is proportional to radiation dose amount but, at the same time, is affected by the extent of ultraviolet-ray excitation in each measurement. In other words, the amount of light emission from a xenon flash lamp, used as an ultraviolet-ray excitation light source, as is in this unit, involves deviation that can hardly be ignored every measurement time. A method to effectively eliminate this error inducing factor was newly and successfully invented by adopting a certain operational circuit.

Its operational principle, as shown in **Fig. 6**, is such that, when measurement is initiated, a reference glass begins fluorescence light emission accompanying light source being lit up. The resulting photo conversion current is, thereupon, accumulated until its integration value reaches a certain constant, where-

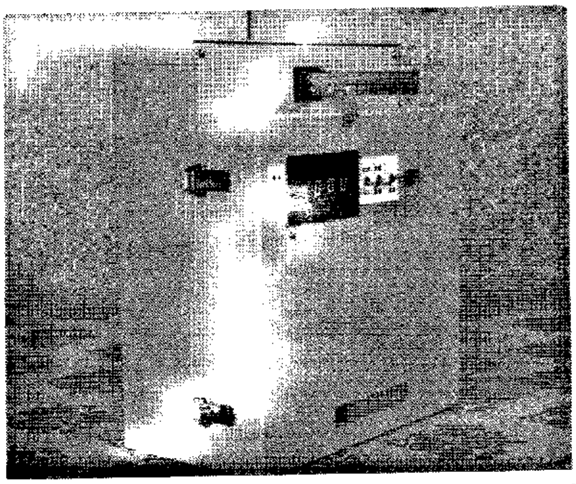

Fig. 4. Toshiba digital fluoro-glass dosimeter, Model FGDP-7

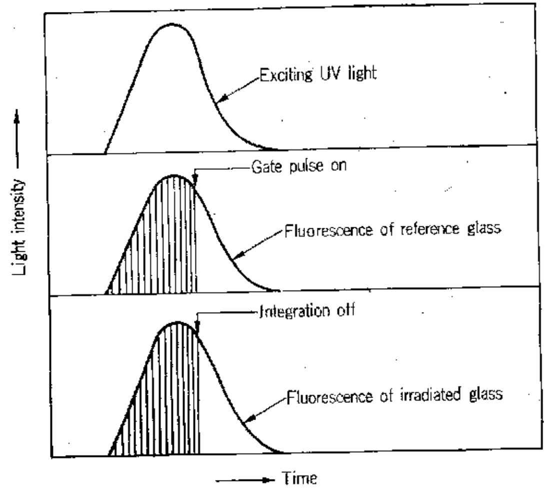

Fig. 6. Measurement sequence

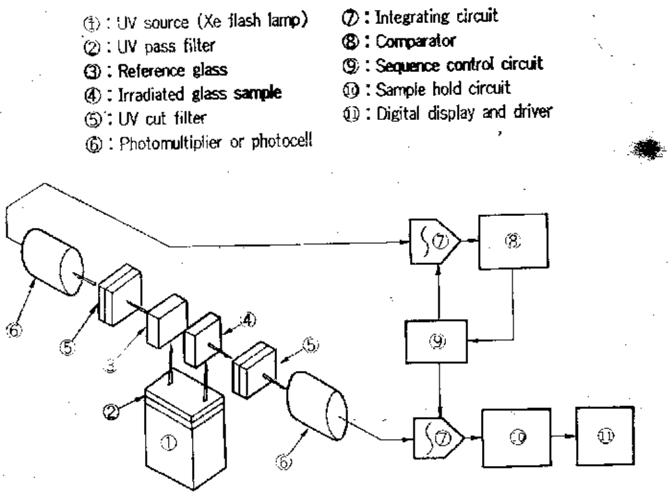

Fig. 5. FGDP-7 schematic diagram

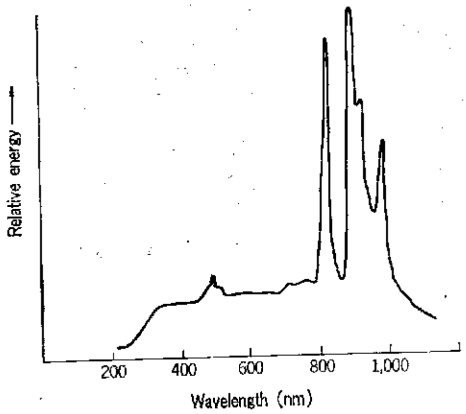

Fig. 7. Relative Xe-lamp spectral energy distribution

upon integration operation is terminated, instantaneously. As a result, the accumulated amount of light flux emitted on this reference glass side becomes always a constant.

On the other hand, photo conversion current measurement operation on the measurement object dosimeter glass side is coincided with that of the reference glass side with respect to its integration operation initiation and termination. Namely, in response to a single time pulsation light emission from a xenon flash lamp that comprises a common ultraviolet-ray generating source, fluorescence light measurement is initiated on both reference glass side and dosimeter glass side, simultaneously. When the accumulated fluorescence amount on the reference glass side reaches a certain constant, a gate signal is transmitted from a comparator and then integration operation is terminated in both circuits.

In this manner, as the amount of light flux emitted on the reference glass side becomes always a constant (equivalent dose value of reference glass), the accumulated amount value maintained on the dosimeter glass circuit side shows an accurate radiation dose amount with no division operation circuits being needed.

The reason is that this accumulated amount value corresponds to a value over an integration period that always holds a constant light amount being emitted from the light source.

The next important mechanism is filter construction adopted in this unit. Xenon lamp spectral energy distribution has a strongly peaked spectrum over visible and infrared ranges as well as, obviously, in an ultraviolet range, as shown in **Fig. 7**. Among them, those other than the ultraviolet range, that falls in the intent of usage, may possibly cause a noise in measurement due to lighting leakage. Namely, the radio-photoluminescence (RPL) coming from a dosimeter glass exposed to radiation has a peak at a 590 to 600 nm level. A photomultiplier having high sensitivity in this range or a photo-diode whose sensitivity peak matches this level is used as a sensor, in particular.

Therefore, in order to achieve effective optical system operation, a color filter, as shown in **Fig. 8**, is used. As ultraviolet-ray excitation light source needs its ultraviolet rays to be as sharp as possible in its energy spectrum, having a peak at 365 nm, as is shown

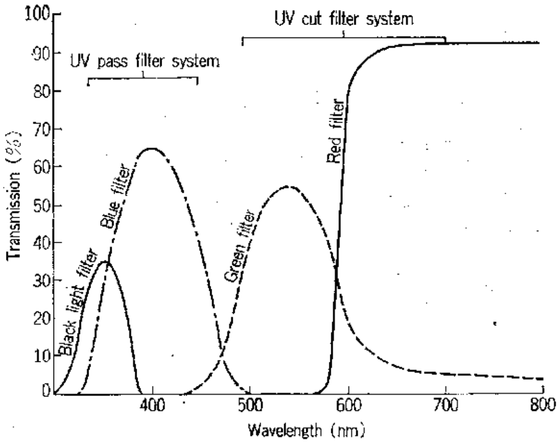

Fig. 8. Spectral characteristics for various filters

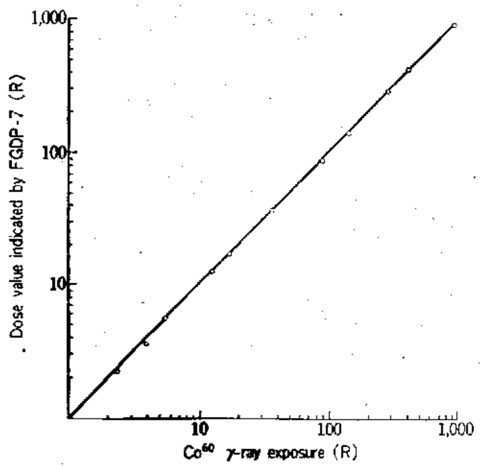

Fig. 9. Linear relationship between exposure and measured dose

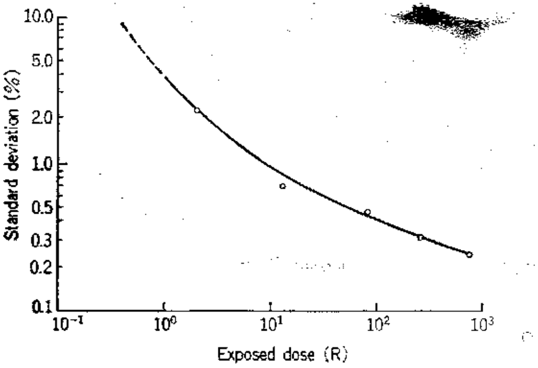

Fig. 10. FGDP-7 reproducibility in dose reading

in a filter illustrated in a section denoted as ② in **Fig. 5**, a black light filter that passes ultraviolet rays alone and copper and cobalt contained blue filter are used in combination. By using two filters combined, as shown in **Fig. 8**, only sharp ultraviolet rays having a small peak width are passed, eliminating extra visible and infrared range rays.

Moreover, in front of a photomultiplier (or a photodiode), a red filter that filters rays in visible light range and green filter that prevents a xenon lamp from emitting a strongly peaked light in the infrared light range, are used in combination. The colored section, as illustrated in **Fig. 8**, incorporates passing only useful light, enabling accurate measurement of radiophotoluminescence having a peak at 590 to 600 nm level.

Measurement Accuracy and Reproducibility

The FGDP-7 enables direct digital radiation dose measurement in a range from 200 mR to 2,000 R with no correction being provided.

Figure 9 shows plotted measurement data from the FGDP-7, in comparison to radiation dose obtained by providing reference irradiation on FD-7 glass using Co^{60} γ rays. As is apparent from the figure, these data are plotted exactly on a line that is drawn from a zero point to a 1,000 R point, indicating excellent linearity.

In addition, with respect to ten pieces of FD-7 glass (8×8×4.7 mm), reference irradiation was conducted at each respective radiation dose level using Co^{60} as a radiation source. Measurement was repeated 10 times per specimen. Measurement results are indicated in **Fig. 10** with small relative standard deviation.

Although measurement data deviation becomes a little larger in a range less than 1 R, those data in a range greater than 10 R become less than 1% in relative standard deviation. This reproducibility indicates that this dosimeter is amazingly accurate, as compared with other solid element dosimeters, such as film badge, TLD etc. It is assumed that pulse emission measurement method, that utilizes glass dosimeter's special features to the best extent, exhibited best effects and capabilities.