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STUDIES ON THE POCKET DOSIMETER FOR PREVENTION OF RADIATION INJURIES

2. FILMBADGE DOSIMETRY AND PHOTOGRAPHIC ACTIONS OF X-RAYS

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Owing to the recent remarkable frequency of utilization of radioactive substances and mass radiography, many operators including X-ray technicians working in clinics have been exposed to radiations of various qualities. It is clear that they are being threatened with danger of radiation injuries. Different radiation sources with many diverse qualities are handled in various fields such as physics, chemistry, agriculture, medicine etc., adding to the difficulty of detection of radiation injuries.

According to the International Recommendations on Radiological Protection (1950), the maximum tolerance dose of external X- or γ-radiation on human skin surface is stated to be 0.5r per week. The letter "r" as used here stands for "roentgen" which is a unit of radiation dose, and denotes a quantity of X- or γ-radiation producing (+) and (−) ions carrying 1 e.s.u. quantity of electricity in air at each 0.001293 gm of air. This roentgen unit is measured indirectly by degree of ionization of air by X- or γ-radiation. Taking into consideration of the additional, 0.3r per week measured in the space corresponds to the maximum tolerance dose, since intradenual scattering rays are added to those acting upon the skin surface.

At present a number of methods are available for radiation measurements, e.g., the gas ionization method in which one measures the electric charge of ions produced by ionization of air within the chamber, the filmbadge method measuring optical density of films, or the methods employing Geiger-Müller counter and scintillation counter for γ-radiation.

The gas ionization and the filmbadge methods are used most extensively for prevention of radiation injuries. With either of the two methods, however, the efficiency with which energies of incident radiation are transformed into ions or blackening of films should be considered. In practice the transforming efficiency depends on the quality of the incident radiation. If the figures indicated by the measuring apparatus will differ in accordance with radiation quality, we call such a phenomenon the wavelength dependence of the apparatus. I have reported in Part I of the present series of study on the wavelength dependence of pocket condenser chamber, a sort of ionization chamber.[1] In the first paper the wavelength dependence of the film emulsion was briefly described. In this second report we wish to present our discussion on the wavelength dependence of film emulsion sensitivity to X-ray together with some of the results of our experiment.

Mechanism of Photographic Action of X-ray or γ-ray

The blackening of photographic emulsion by visible ray, as is well known, depends upon the fact that the visible ray photon acts upon the photosensitive nucleus of silver-bromide (AgBr) particles of emulsion and builds the latent image, and then the reducing agent of developer acts upon the silver-bromide to form silver particles (Fig. 1). Action of X-ray on photographic emulsion, which had offered a key to the discovery

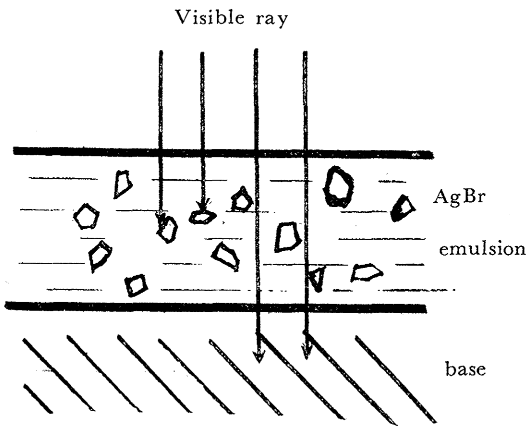

Fig. 1 Visible ray incidence: linear absorption energy is used for formation of latent image.

of X-ray itself, are similar in their mechanism to the photographic action of visible ray owing to the fact that the X-ray, like the visible ray is a sort of electromagnetic wave. The only difference between the two rays is that the X-ray energy is of higher value than the other. Since, however, the energies of both these rays lie within the higher value range, there occurs a characteristic energy absorption due to the atomic structure of silver and bromine, and the secondary radiation phenomena such as Compton effect, photo-electric effect, and classical scattering. A schematic illustration of the action of X– or γ–ray at its incidence into the emulsion is given in Fig. 2.

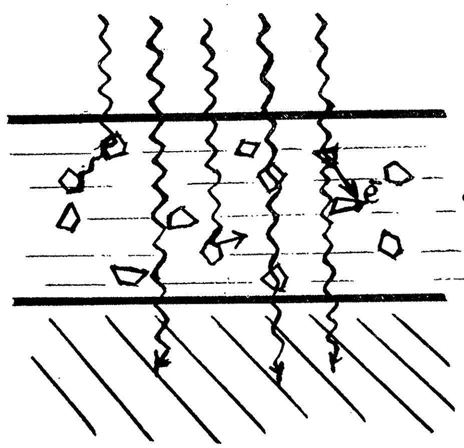

Fig. 2 X– or gamma–ray incidence : absorped energy transformed into Compton– or photelectric effect, each particle having an ability of latent image formation.

Wavelength Dependence of Film Blackening by X–ray or γ–ray

The atoms absorb especially a part of incident ray corresponding with wavelength of absorption edge owing to their characteristic absorption edge. In the photographic sensitive emulsion, the silver and bromine particles have large absorption place discontinuously at their characteristic wavelength, and the blackening of films are large at these wavelength regions. There are many reports and studies about these phenomena. Fig. 3 illustrates that the absorption edge of silver and bromine are shown by two peaks of the curve, and the blackening curve of film shows the discontinuous peaks. And the wavelength of absorption edge of silver is 0.485 AE and of bromine is 0.918 AE.

When X– or γ–radiation incident into the layer of x thickness with energy E_0, the absorpion energy E_{abs} beeing absorbed by this layer, is shown by follwing equation,[2)3)4)5)]

$$E_{abs} = E_0(1-e^{-\mu x})\left(\frac{p\tau}{\mu} + \frac{\sigma}{\mu}\right)$$

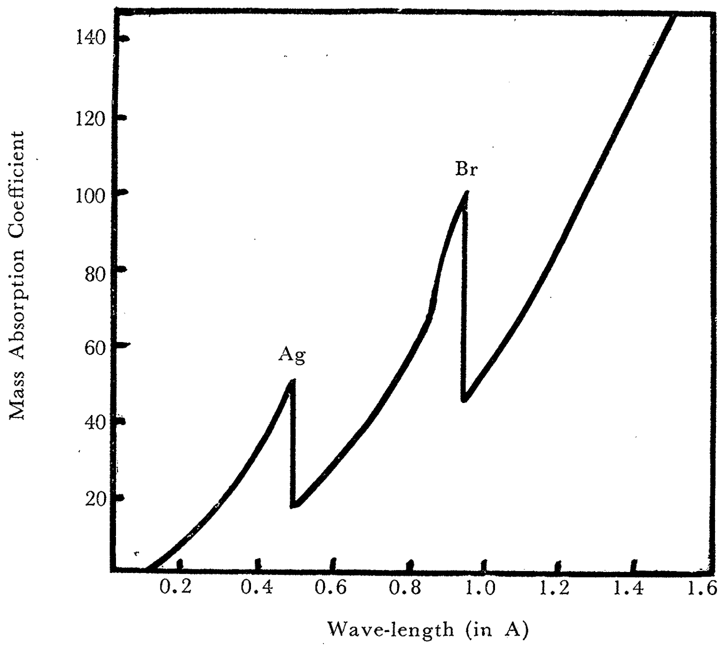

Fig. 3 Silver bromide X-ray absorption curves.

where τ is the photographic coefficient, σ the recoil coefficient, and p photoelectric yield and μ linear absorption coefficient. Part of energy which absorbed in the relation participates in photographic action. If this layer is photosensitive emulsion, energies of photo- and recoil-electrons are absorbed in gelatin layer of photographic emulsion, and such energies are utilized for making of latent image. Therefore the energies taking part in the photographic effect are correlated with the thickness of emulsion and with the absorption coefficient. The photographic effect will further depend on the quality of incident ray because μ is the function depending upon the radiation quality of the incident ray. Namely the blakening of the film by X- or γ-ray have not the linearity with quantities of the incident ray owing to the absorption edges of silver and bromine particles below 60 kVp, and above this energy, the recoil- and photo-electrons become the great cause of wavelength dependence.

There are Seemann's studies on wavelength dependence of 0.2 AE~2.5 AE regions,[2] Hoerlin's studies 0.01 AE~1.3 AE regions.[3] And emulsion thickness has been reported by Glocker,[5] Hoerlin,[3] ect.. In E. E. Smith's[6] paper has been shown the relationship of blackening and half value layer of incident radiation on four kinds of films. Hoerlin and Müller applied to X-ray or γ-ray the sensitization of gold compound which had been used to visible ray because the photographic action of X-ray or γ-ray depends greatly on the second electrons.[7] And they reported the sensitizing factor increase from 1.5 at 1.3 AE to 10 at 0.011 AE ray. E. E. Smith has reported on the wavelength dependence of a few varieties of film when exposed to X-ray and electron beam. Fig. 4 is a reproduction of a part

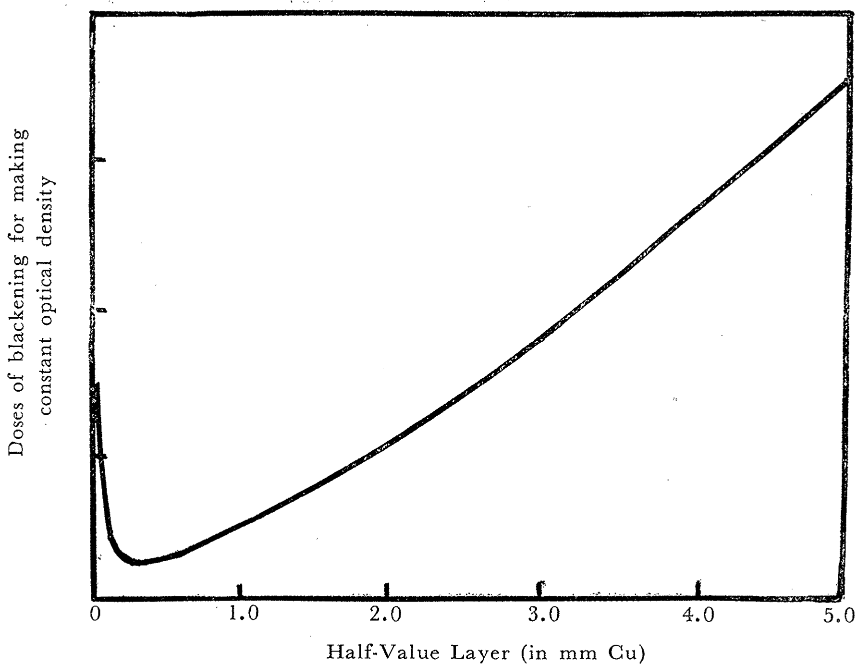

Fig. 4 Energy dependence of film blackening

of his paper showing the doses and qualities of radiation required to indicate 0.5 optical density. The film used was unscreened and showed maximum sensitivity with radiation quality of half value layer of Cu 0.2 mm.

Methods and Results

Our experiments were concerned with wavelength dependence of film emulsions. For radiation source we used a deep therapy apparatus (Greinacher's circuit), the films were made by Sakura X-ray Film Co. and Fuji Film Co.. For one set of tests all the necessary pieces were obtained from one film 10×12 in. size. Developer was SDX-1 diluted 5 times, and simultaneous development for 3 minutes at 16°C was done. Focus to film distance was 120 cm, for minute roentgen dose was measured accurately with Standard Dosimeter (made by Shimazu Co.), and the exposure time was so regulated as to assure 0.5 r dose for each tube voltage.

TABLE I

Energy dependence of blackening for constant quantity 0.5r. Film : SAKURA X-ray film, Developer : SDX-1, 5 times dilute, 16°C, 3 min., Simultaneous developement.

Tube Voltage in kVp.	Filter in mm	r/min. at 120 cm	Expos. time for 0.5r	Optical Density
80	Al 1.0	0.73	41.0sec	0.87
90	Al 2.0	0.79	38.0	0.82
100	Al 2.0	0.97	31.0	0.78
120	Cu 0.3 + Al 0.5	0.77	39.0	0.71
140	Cu 0.3 + Al 0.5	1.03	29.0	0.70
150	Cu 0.5 + Al 0.5	1.17	25.6	0.57
160	Cu 0.5 + Al 0.5	1.19	25.2	0.63

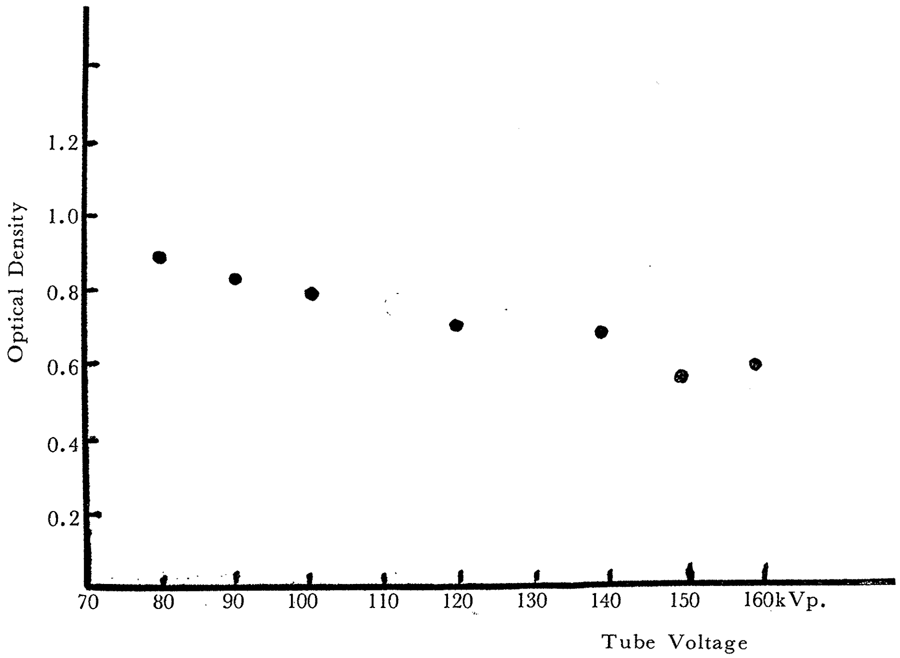

Fig. 5 X-ray quality dependence of blackning (by Table I).

Test pieces were wrapped doubly with black papers and kept at a distance more than 1 meter from the walls to avoid back scattering. Same films were then developed under the conditions described previously, the degree of blackening was read by the photoelectric densitophotometer. The results are presented on Table I and Fig. 5. The incident ray quantity was the same, the film blackening was more intense with the soft than the hard rays. Fig. 5 is schematic representation of the Table I. Abscissa represents

TABLE II

Dependence of blackening on radiation quality (various workers). These values were obtained from the Fig. 6. Developing condition is the same as for the Table I.

Tube Voltage	Doses for Optical Density 0.7		Doses for Optical Density 0.5	
	SAKURA Film	FUJI Film	SAKURA Film	FUJI Film
80 kVp	0.40 r	0.24 r	0.25 r	0.14 r
160	0.64	0.42	0.40	0.24

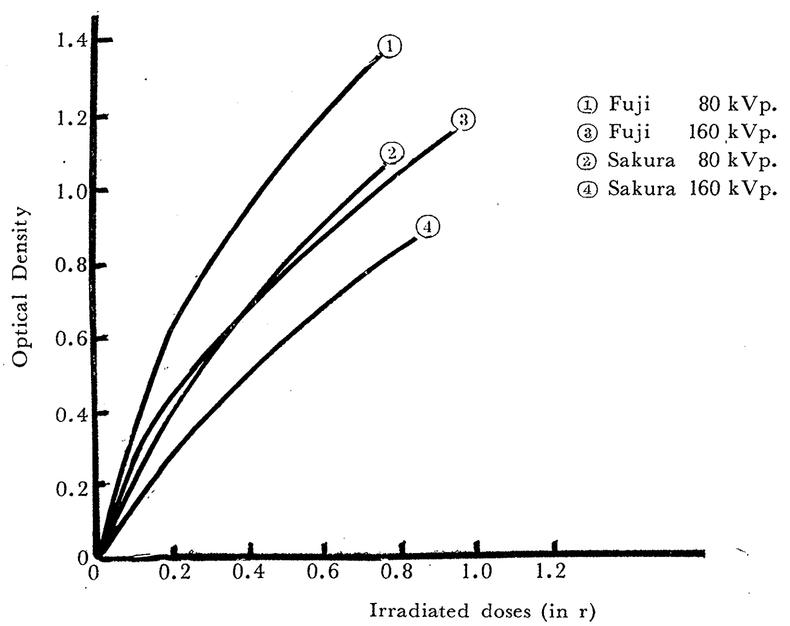

Fig. 6 Blackening curves of two manufactures films, developed simultaneously by the same developer.

tube voltage, and since different filter was used for each tube voltage, we feel that joining each point on the abscissa with a curve line is not appropriate. Fig. 6 shows comparison of the special characteristics of the film made by two films, Sakura and Fuji Film Manufactures, the figure presents the curve of the optical density with varying doses from 80 kVp (filter: Al 1.0mm) to 160kVp (filter: Cu 0.5mm + Al 0.5mm). And we can compute from such curves the quantity of both radiation quality that is necessary for a certain degree of film blackening. Table II represents the figures computed from the Fig. 6, and shows the quantity to get the real optical density of 0.7 and 0.5 on 80 kVp and 160 kVp with two sorts of films. It is quite clear on this table that the hard ray needs larger doses than the soft ray to obtain the same optical density. These films were treated under the same conditions as former.

Summary

For prevention of radiation injuries it is important that the operator is constantly and accurately aware of the radiation dose to which he is exposed. In order to measure the radiation dose he is receiving it is most advantageous for the operator to carry the measuring instrument on himself. Pocket dosimeter and film badge, were made for this purpose and are being quite extensively used. From the nature of its mechanism for radiation test its wavelength dependence is unavoidable, as we have already reported in the previous paper.[1)] In the present report we have discussed the wavelength dependence of film emulsion and described a part of the experiments performed. In blackening of the photographic emulsion of film the action of secondary electrons such as Compton electron, photoelectron, classical scattering (Thomson scattering) augment that of the incident ray. The yield of secondary electrons depends moreover on hardness of the incident radiation, thus, the optical density does not correspond with the roentgen unit which is based on the energy absorption by the air even the hardness of radiation quality and optical density vary on the linear part of sensitivity of the film.

According to our experiments with constant exposure (under 0.5r irradiation) the film blackening degree was 0.87 at 80kVp, and 0.63 at 160 kVp, whereas the radiation quantity necessary to the optical density of 0.7 at 80kVp was found to be 0.40r, and at 160kVp it was 0.64r (Sakura film under certain developing conditions).

The authors are hoping to make improvements on the accuracy with which the radiation quantity received by the operator is measured, as determined by the film blackening method.

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