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PHOTOGRAPHIC FILM AS A POCKET RADIATION DOSIMETER

by

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INTRODUCTION

An air ionization chamber is theoretically the ideal type of radiation dosimeter since the roentgen is defined in terms of the ionization in air. When it comes to the continuous monitoring of a large number of people for radiation exposure, however, the practical problems of handling and servicing the meters must be considered in the choice of a method for carrying out such monitoring.

Dental films have been used for a long time as a means of obtaining qualitative information regarding individual exposure to x-rays and gamma rays. The blackening of a film, however, varies by such a large factor for radiations of various quantum energies that this method could not be considered satisfactory unless some means of compensation for this energy dependence of response were achieved. A good pocket dosimeter should have the following properties:

1) Response for equal exposures in roentgens should be, as far as possible, independent of the quantum energy of the radiation.

2) The range of the meter preferably should be such that doses from less than 0.1 r to 10 or 20 r should be accurately measurable.

3) The response should not be producible by agents other than the radiations to be measured.

4) It should be small and light and should permit of being handled in large numbers by technicians.

ENERGY DEPENDENCE OF FILM BLACKENING

Photographic blackening is defined as the negative logarithm of the ratio of the intensity transmitted through the exposed film to that transmitted by a similarly developed unexposed film: or

$$B = -\log I/I_0 = \log I_0/I$$

Plotting blackening against energy of quantum radiation for fixed exposure in roentgens we get the curves shown in Figure 1. The solid curve shows the response of a standard dental film when exposed to 0.5 r of quantum radiation without a filter. The fact that the blackening increases rapidly as one goes to radiation of lower quantum energy suggests that the response for a given dose would be more nearly independent of the quantum energy if an absorber were placed over the film. The broken curve gives the response when 1 mm of Cd is used as a filter without changing the intensity of the primary beam. The dashed curve gives the response one calculates for the same absorber. If one calculates the response for a Cu filter 2 mm thick the results are not altered appreciably except in the range 50 kv to 60 kv. The useful lower limit would remain at 60 kv approximately. Below this value the film response cannot be satisfactorily compensated by a single filter.

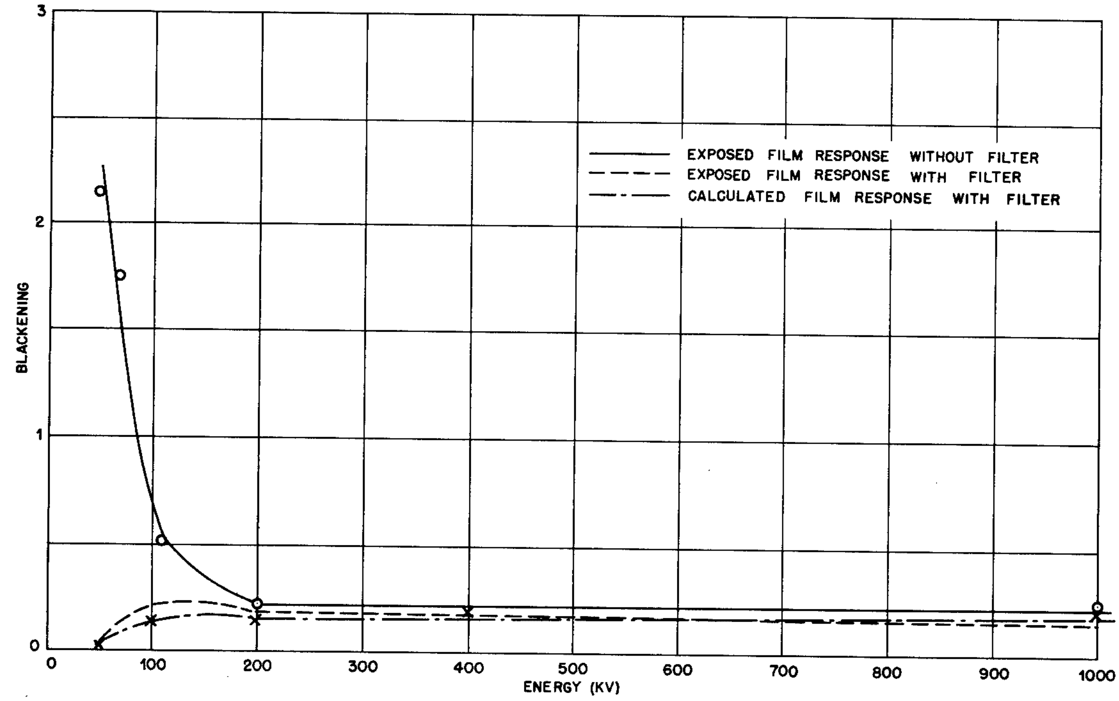

Figure 1. Blackening versus energy for fixed exposure.

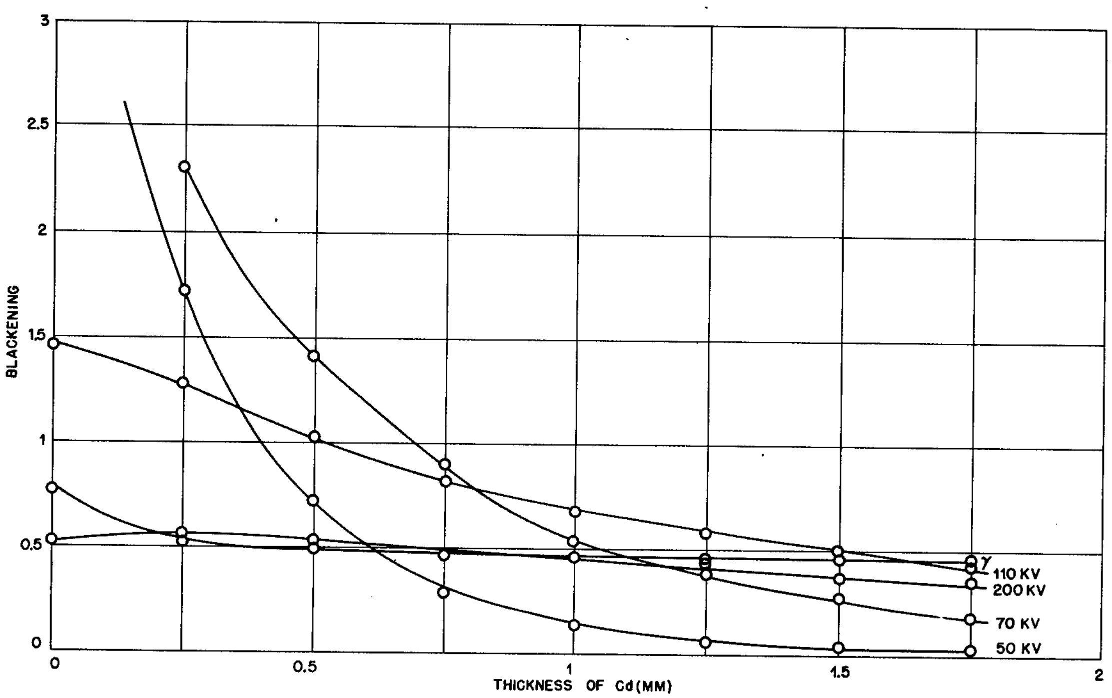

Figure 2. DuPont No. 502 film exposed at 0.5 r.

In the many studies made to find the best filter material and thickness, Pb, Ag, and Cd were tried. Pb was considered bad because absorption becomes very large at 87 kv; i.e., the K absorption edge comes at this energy. Ag and Cd are better in this respect since their K absorption edges come at 25.5 kv and 26.6 kv respectively. As we did not use monochromatic radiation this feature was not brought out very clearly in our results. Ag and Cd are equally satisfactory as filters. Cd was chosen, however, because it is not expensive and it is easy to work.

The method of finding the thickness of absorber was as follows. Step absorbers from 0 to 1 or 2 mm in thickness, depending on the material, were used. Films were exposed through these absorbers to a given dose of quantum radiation of energies ranging from 50 kv x-rays to the gamma rays for each energy. For duPont film No. 502 one obtains a family of curves as shown in Figure 2 from which the proper filter thickness may be chosen. It is seen that for this film a filter thickness slightly in excess of 1 mm would be optimum; 1 mm was chosen because there is an additional 0.5 mm of iron in the badge. Figure 3 shows the energy dependence of this film when 1 mm of Cd is used as filter. For duPont film No. 351 the energy dependence for a 1 mm Cd filter is shown in Figure 4. Both films give a satisfactory response from hard gamma rays down to 100 kv quantum energy and are useful down to about 60 kv.

EXPOSURE RANGE OF FILMS

duPont No. 502 is typical of the most sensitive films obtainable for this use from Eastman and duPont. Figure 5 gives a curve of blackening versus exposure in roentgens up to 3 r, over which range the curvature is not bad. A Ra source was used. The smallest blackening that can be measured with any reliability corresponds to about 0.03 r. The total useful range of a film meter can be extended by the use of a second less sensitive film. For this duPont No. 351 has been chosen. Its blackening versus exposure curve is shown in Figure 6. With these two films exposures from 0.03 r to 20 r can be measured reliably. Fortunately, with x-rays and gamma rays there is no significant departure from the reciprocity law in the useful range. With visible light however there is an inertia region followed by a linear part if blackening is plotted versus the logarithm of exposure, then by saturation and perhaps reversal.

MONITORING RADIATION WITH FILM

The plan in use requires the worker to carry an x-ray film of dental packet size in a badge of light weight designed for the purpose. The photographs in Figure 7 show the parts of the badge. Besides protecting the film while it is worn, it divided it into three parts. The middle portion has the necessary filter (1 mm of Cd) to give a fairly uniform response over the range of wavelengths indicated.

On opposite sides of the center part are regions for detecting soft radiation and for numbering the film by means of x-rays. The section for detecting soft radiation exposes the film packet through windows in the badge. This section will certainly be useful in indicating the absence of beta rays and quantum radiation. It may be possible to calibrate this unfiltered area when the nature of the radiation is known. One of these windows carries the badge number printed on paper covered by cellophane. The same number is perforated in the Cd in the lower part of the badge. This makes it possible to use x-rays to number the film before it is removed from its badge.

Development can then be carried out without delay involved in keeping large numbers of films in identifiable order during the developing process. Except for angular dependence at long wavelengths, it is immaterial which way the badge is turned toward the beam. This accomplished in the design of the badge and by using dental packages without the usual metal foil.

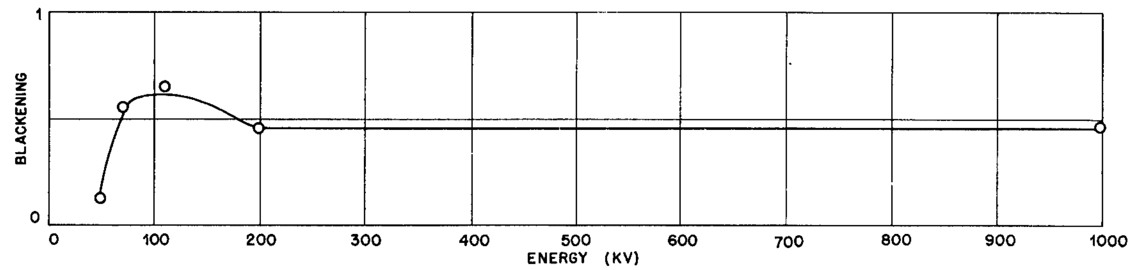

Figure 3. DuPont film No. 502 exposed to 0.5 r — 1 mm Cd filter.

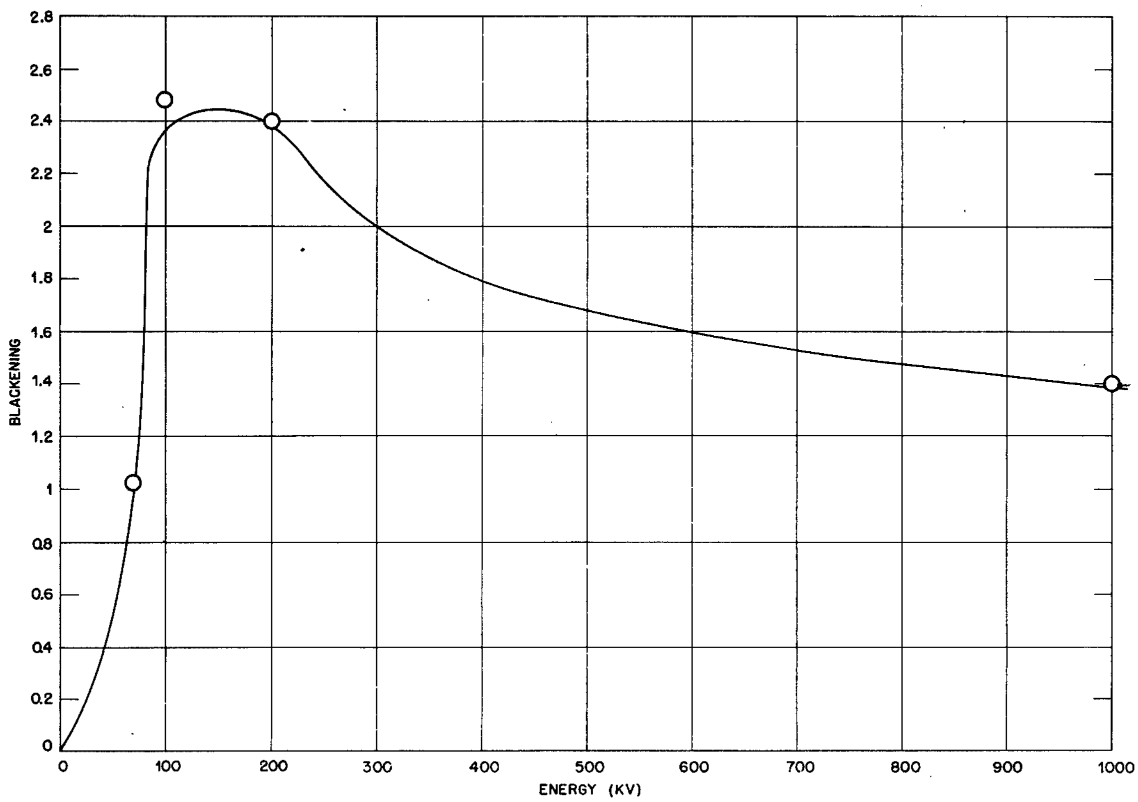

Figure 4. DuPont film No. 351 exposed to 10 r — 1 mm Cd filter.

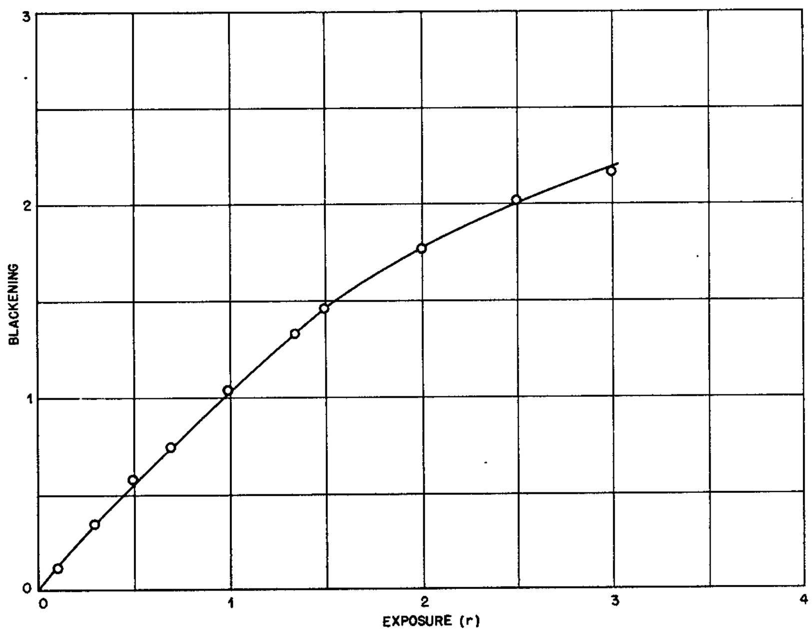

Figure 5. Blackening versus exposure for No. 602 duPont film.

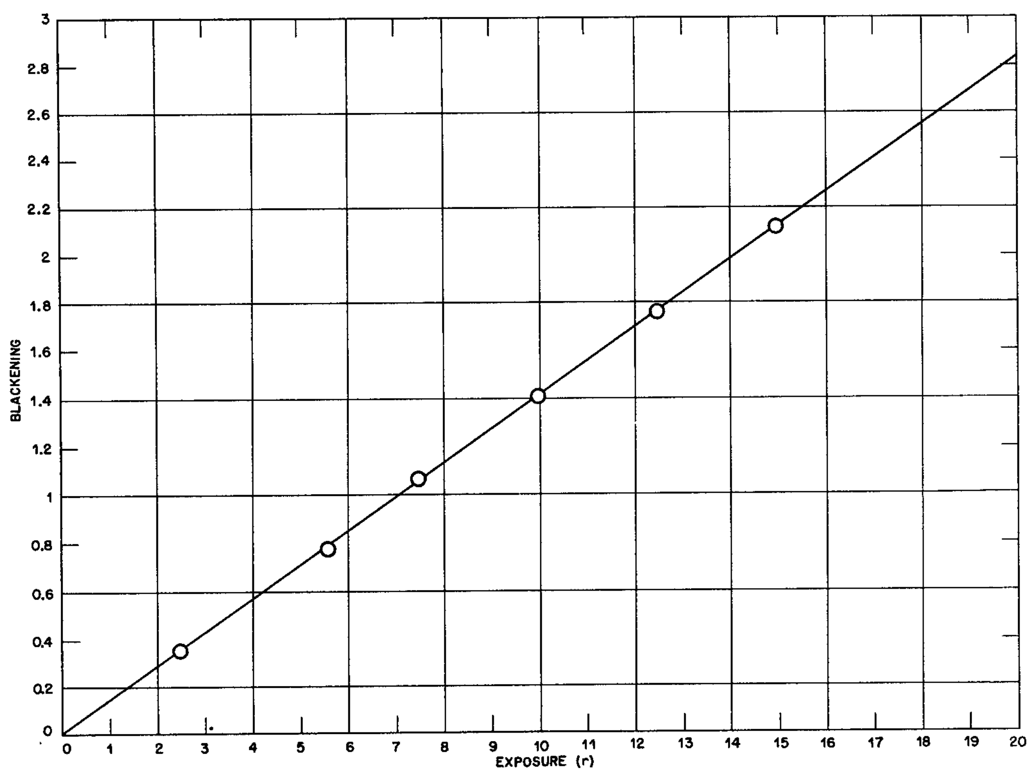

Figure 6. Blackening versus exposure for No. 351 duPont film.

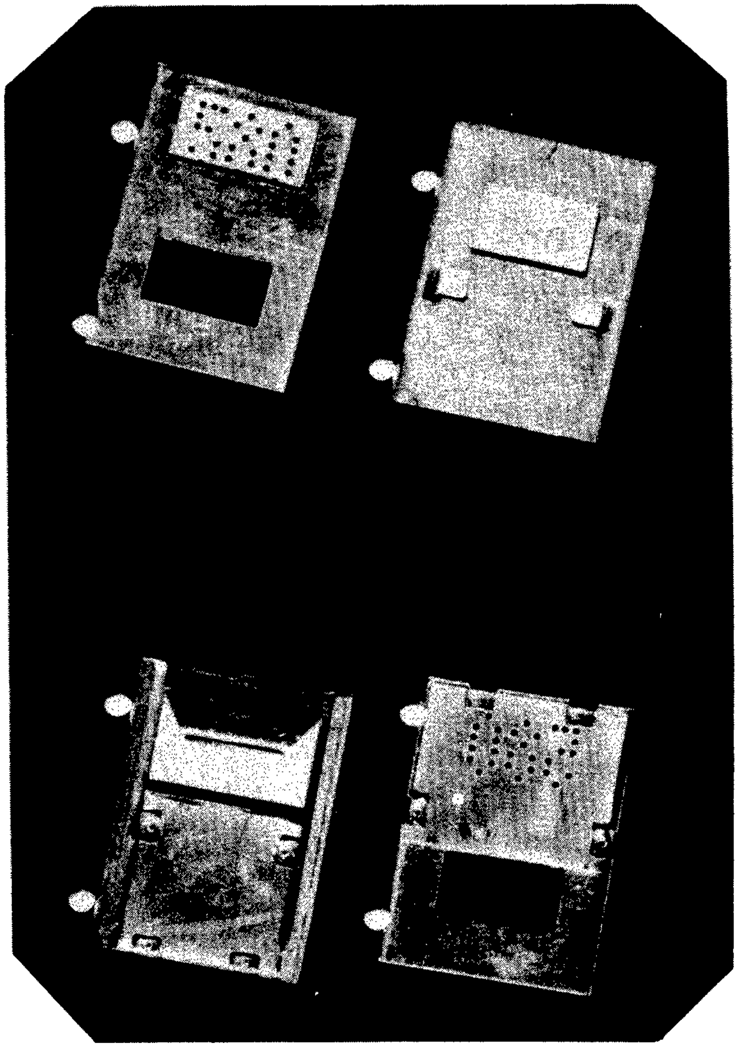

Figure 7. Parts of the film badge.

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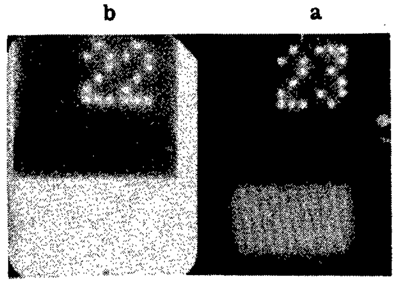

Figure 8. Two duPont No. 502 films exposed to 0.5 γ, (a) by gamma rays from Ra and (b) by 200 kv x-rays.

As in all photography the conditions of developing are important. Temperature must be held constant and the time in the developer always must be the same for comparable results. Fixing and washing are not so important but it does not hurt to use controlled and reproducible conditions here. Still another factor must be watched. There is a decided dependence on depth in the developer if it is old and is not agitated. Developer should be replaced frequently and it should be stirred while in use. Accuracy is increased if films of known exposure are carried through the development simultaneously with the unknowns.

Figure 8 shows two No. 502 films exposed to 0.5 r, (a) by gamma rays from Ra and (b) by 200 kv x-rays. These are prints of the original negatives. While the photography does not preserve all the features of these negatives, it is evident that the films are permanently marked. Also it can be seen that the regions of interest in the middle of the films have comparable blackening. Measurements on the original films confirm this.

Measurements on blackening are made on a model No. 500 Photovolt densitometer which is found to be quite satisfactory if operating voltages are held constant.

DISCUSSION

In deciding the conditions to be met by a large scale radiation monitoring program, the things to be accomplished have to be considered. Obviously, the primary purpose of any such program is to eliminate as far as possible radiation injury to personnel. Such injuries can result from large single exposures or they may arise from the accumulation of small doses. In either case the effects may not be apparent for some time; in some instances of the accumulation type, many years may elapse before the injury of the first doses are felt.

On account of the nature of the hazard one can add two corollary objectives: (a) a reasonably diligent radiation monitoring program would tend to take responsibility from those providing it for injuries traceable to radiation exposure at some earlier time; (b) a good record of exposures may be useful in reducing the limits of uncertainty of the tolerance dose. To accomplish the chief objective it is desirable to keep exposures whenever possible below the best estimate of the tolerance upper limit, but when an exposure goes outside this range its value should be known. A film meter with its range up to about 20 r will lose very few exposures. Its accuracy in routine measurements is believed to be better than 25%. In this latter regard it compares quite favorably with pocket chambers and it does not have the present range limitation (0.2 r)of these instruments. There should not be so many spurious readings as with pocket chambers where leakage, jars, and tampering produce the same effect as radiation.

The reliability of film meters will not change with time, and film blackening almost certainly will be the result of radiation. Pocket chambers excel in allowing the integrated dose to be read quickly. This is an important advantage when one wishes to follow an exposure during the course of an experiment or any other job where the material handled is known to be very active. Until a single method with the advantages of both films and ion chambers is developed there will be a need for using both types. At the present time no routine method is available which measures exposures to a high degree of accuracy. If the worst were true, however, and the accuracy were no better than 50%, the effort would still be justified.

Pocket meters can, of course, not be expected to replace radiation surveys which should be made regularly in order to establish the general radiation conditions which prevail in the areas. These are necessary for finding high local intensities such as beams from imperfect shields, and beta ray sources for which the present pocket meters are not designed. Special surveys must take care of fast neutron radiation and atmospheric contamination.