Evaluation of the Response of Film Badges to High Energy Photons

NIOSH/DCAS

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In response to a question raised during GSI work group discussions, NIOSH has evaluated the relative response of dosimeter film to the high energy bremsstrahlung photons produced by an electron accelerator.

Source Term

The electron accelerator, or betatron, produces high energy electrons which in turn produce spectrum of bremsstrahlung photons which vary in energy up to the maximum energy of the electron. The energy range of the spectrum depends on the accelerating voltage of the machine. The electron energy of betatrons generally range from 20 MeV to 35 MeV.

The energy distribution of bremsstrahlung x-ray photons for 20 MeV and 24 MeV electrons is shown in Table 1 below.[1]

Table 1

Energy Region MeV	Intensity,% 20 Mev	Intensity, % 24 Mev
0-3	69.23	65.3
3-5	11.29	11.43
5-10	12.66	12.65
10-12	2.71	2.89
12-14	1.98	2.22
14-16	1.3	1.77
16-18	0.67	1.46
18-20	0.16	1.14
20-22		0.62
22-24		0.25

For electrons 20 MeV electrons, 96 % of the photon intensity is in the 0 to 12 MeV range. The 24 MeV electron, has 92% of the photon intensity in the 0 to 12 MeV range.

Dosimeter

A radiation monitoring dosimeter is made up of photographic emulsion and a holder which incorporates filters made up of differing density materials to smooth energy response. The emulsion darkens with photon exposure. This darkening or density is a function of intensity and energy of the photons.

The emulsion is essentially made of silver halide and a substrate. Table 2 provides the composition of emulsions from several manufacturers in the early 1960s[2]. The compositions are similar with some variation based on the particular type of radiation to be detected.

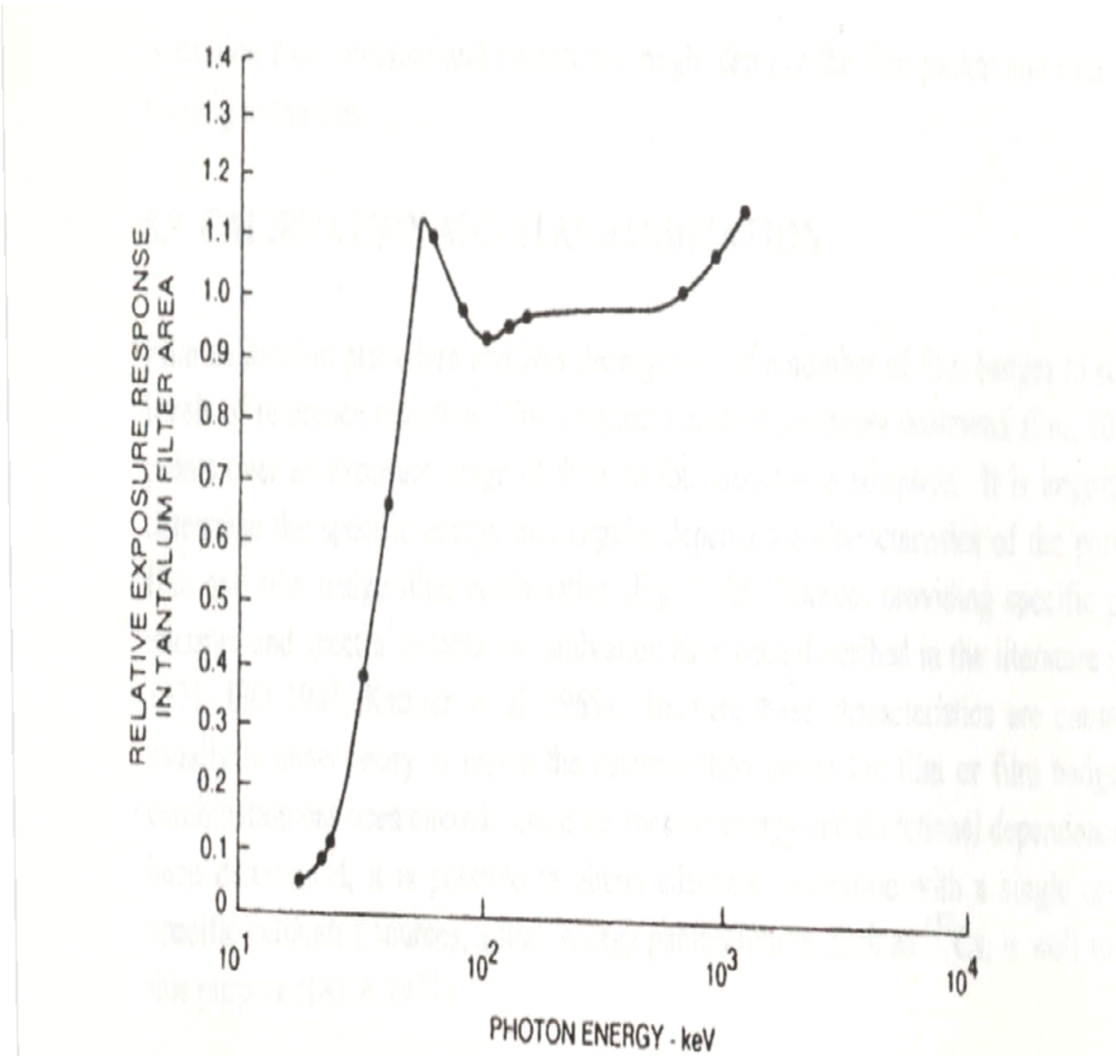
Table 2

CHEMICAL COMPOSITION OF CERTAIN NUCLEAR EMULSIONS[a]

Substance[b]	Ilford G, K, L series (58% R.H.)	Eastman NTA & NTB (50% R.H.)	Eastman NTC (50% R.H.)	Eastman NTB-4 (50% R.H.)	Fuji ET-7A (65% R.H.)	Agfa-Wolfen K-2 (60% R.H.)
Ag	1.817	1.35	0.74	1.755	1.74	1.76
Br	1.338	0.97	0.53	1.335	1.26	1.29
I	0.012	0.04	0.02	—	0.049	0.05
C	0.277	0.29	0.40	0.289	0.278	0.29
H	0.0534	0.05	0.07	0.0534	0.0344	0.06
O	0.249	0.39	0.46	0.313	0.161	0.30
N	0.074	0.09	0.11	0.0764	0.010	0.07
S	0.007	—	—	—	0.015	0.02
Total	3.8278	3.19	2.34	3.8218	3.75	3.84
Silver halide	82.8%	74.0%	55.0%	80.8%	81.3%	80.8%
Gel phase	17.2%	26.0%	45.0%	19.2%	18.7%	19.2%

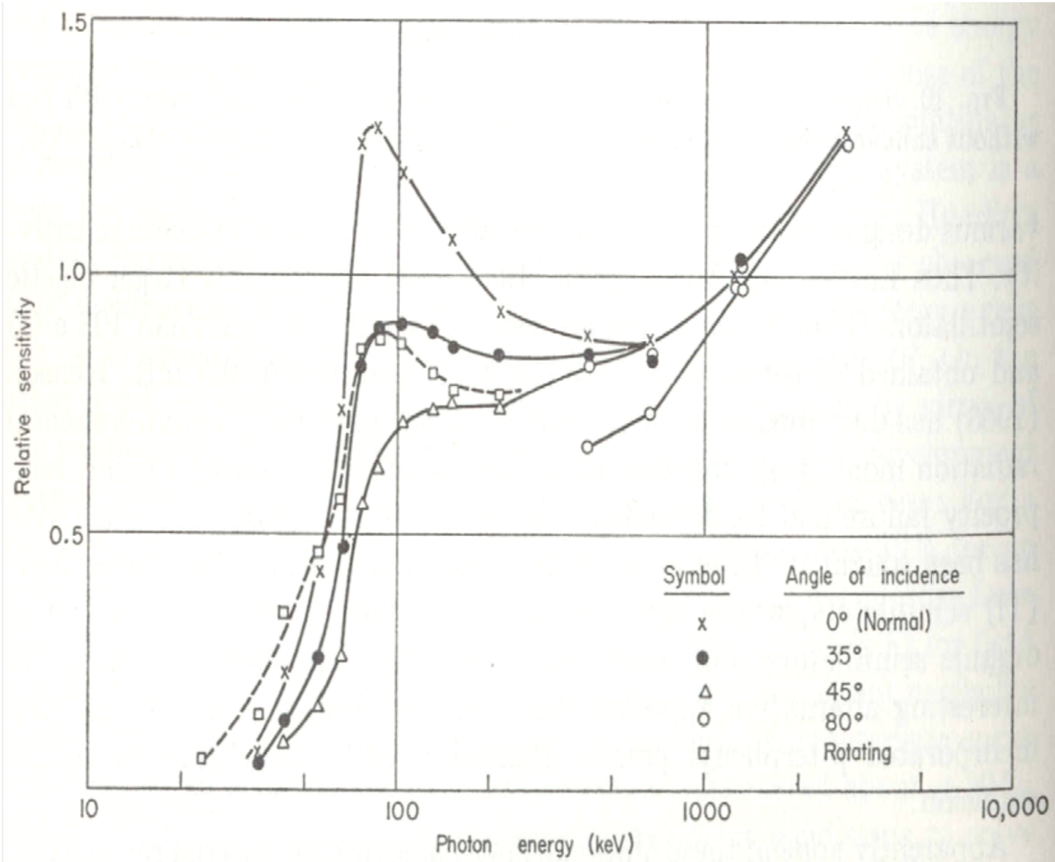
The film holder consists of a structural base and a set of filters. The number and type of filters provide information on the energy and type of radiation to which it is exposed. The filters consist of bare film, plastic and varying density metal. Of particular interest is the response of the film under metal filters to high energy photons. As the photon energy increases the density under the metal filter is greater than that of bare film. Figures 1 and 2 below, which were taken from Attix[2] et al. and Yoder and Zelac[3], illustrate this effect.

Figure 1



Film response with 0.020 inch tantalum filter (adapted from Brady and Iverson 1968)

Figure 2



Relative sensitivity of Kodak RM film as a function of photon energy and angle of incidence of radiation. Film under filter of 0.71 mm Sn plus 0.31 mm Pb. (Heard and Jones, 1963)[2]

In Figure 2, the normal incidence exposure (0^0), as well as the other angles of incidence, shows the relative sensitivity increasing under the metal filter (Sn-Pb) as a function photon energy. The similar response can be seen in Figure 1 for a different type of metal filter (Ta). This effect is due, in part to the increase of the pair production interaction coefficient with photon energy and atomic number.

Conclusion

Film badges worn in an environment where high energy photons (>1 MeV) are present, such as a betatron, have an increase in response over photons below 1 MeV, with the magnitude of the over response increasing with increasing photon enegy. A dose based on the film density underneath the metal filter would be biased in the high direction.

References

1. Activation Method For Measurement Of Bremsstrahlung Photon Flux Produced By Electron Accelerator, Tran Duc Thiep et al, JINR, Dubna, 2005
2. Attix, Roesch, Tochilin, Radiation Dosimetry 2nd Edition, Volume II Instrumentation, Academic Press, 1966.
3. R. Craig Yoder, Ronald E. Zelac, Film Dosimetry, Chapter 5. Materials from Film Badge Dosimetry in Atmospheric Nuclear Tests, National Academy Press, 1989, National Academy of Sciences National Research Council.