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ABSTRACT

Personnel Monitoring Section, Bhabha Atomic Research Centre, Mumbai, is entrusted with the responsibility of providing a countrywide personnel monitoring to radiation workers using external radiation like X, beta, gamma and neutron. As per Radiation Protection Rules (RPR) of 1971 promulgated by the competent authority the personnel monitoring service is mandatory for all the workers working with radiation. The radiation exposures received by them should be within the limits stipulated by AERB. Nearly 43,000 radiation workers in about 3000 DAE and non DAE institutions using radiation & radioisotopes are monitored, using both the Film Badges and the Thermoluminiscent dosimeters. This report presents various aspects of film dosimetry which was introduced more than four decades ago in the country and also analysis of doses received by the radiation workers in the five year block 1994-1998 covered by film badge service.

FILM BADGE PERSONNEL MONITORING AND DOSE DISTRIBUTION OF INDUSTRIAL AND MEDICAL WORKERS IN THE COUNTRY (1994-1998)

1. INTRODUCTION

In 1957, personnel monitoring service using photographic film dosimetry for Department of Atomic Energy institutions was started by Radiological Monitoring Laboratory and it was housed at Tata Institute of Fundamental Research. Later on the group was shifted to Trombay and named as Radiological Measurements Section. Ever since then the monitoring service was gradually extended to outside institutions. The service increased by leaps and bounds with passage of time and the number of radiation workers monitored over the last four decades has been 1.5 lakh employed in DAE, industrial, medical and research institutions. This service was also extended to few countries beyond the frontiers of national boundaries like Bhutan and Nepal. As a consequence, the multifilter film cassette was modified and redesigned to meet the dosemetric requirements and many related relevant improvements were incorporated in film monitoring ever since.

Currently nearly 43,000 radiation workers in the country in about 3000 institutions are covered using both (1) Agfa Gevaert film and (2) $CaSO_4:Dy$ TLD as dosimeters.. The aim of personnel monitoring is to ensure that the radiation safety standards and dose limits stipulated by regulations are strictly adhered to. It also provides data for epidemiological studies. Based on International Commission on Radiological Protection (ICRP) recommendations, Atomic Energy Regulatory Board (AERB) has stipulated a dose limit of 30 mSv in a year or 100 mSv for a given block of five years starting from 1994 (viz. 1994-1998 or 1999-2003).

With the advent of Thermoluminescence Dosimetery (TLD), in the field of individual/personnel monitoring of radiation workers, the process of switching over from Film Badge Dosimeters to TLD has been carried out gradually since 1978 in a phased manner. The first institution to be covered by TLD was Tarapur Atomic Power Station. The use of film badge dosimeters is still prevalent in many countries throughout the world, for the advantages it has over other dosimeters and will continue for many more years to come.

In this report, details of personnel monitoring service using film badges are presented and the dose distribution among radiation workers from industrial and medical institutions using film badge personnel monitoring service is analyzed for the five year period 1994 to 1998.

2. DESCRIPTION OF FILM AND BADGE

Normally, a film pack consists of about 3cm x 4cm transparent polyester film base (≅200micron thickness) coated on one side with more sensitive (fast) emulsion (grain size ≅2 micron) and the other side with less sensitive (slow) emulsion (grain size ≅1 micron) or having two separate films coated with fast and slow emulsions having different sensitivities. The emulsions are coated on a base of cellulose acetate having thickness of 200 microns. This film is sandwiched between two thin black papers and then enclosed in lightproof special plastic wrapper provided with a flap to facilitate opening of film in the dark room.

The 5 metallic filters namely plastic, cadmium, thin copper, thick copper and lead are embedded in cassettes (Figure-1). The thickness of all the filters is 1 mm except thin copper, which is 0.15 mm. There is a back scattered window provided at the back half of the cassette to record the back scattered radiation from the body and determining the genuineness of the dose. The objective of incorporating these filters is to (a) identify the type of radiation, (b) determine the energy of incident radiation and (c) facilitate evaluation of more than one type of radiation exposures.

X-rays, beta and gamma radiation can be evaluated simultaneously with the help of this filter assembly. The cadmium filter is provided to evaluate the doses recorded by the dosimeter for thermal neutron by $Cd^{113}(n, \gamma) Cd^{114}$ reaction.

Other monitoring devices like TLD monitors can not do the evaluation of neutron dose together with X-rays, beta and gamma radiation.

3. DENSITOMETERY

A PC based semiautomatic film badge reader, designed and developed by us, is being used to measure the optical densities and evaluation of radiation doses. A conventional single beam densitometer is being used to measure optical densities of the monitoring films under the various filter positions. The density output is fed to PC through an interface. The processing of the density data for creation of standard lookup tables and evaluation of personnel doses and creation of ready-to-use end file is done through PC.

Sets of standard lookup tables are created for open, plastic, cadmium, thin copper, thick copper and lead filter positions for gamma, beta, X-radiation of 50, 75, 100, 200 and 250 KVp for both scraped and unscraped films of fast and slow emulsion combinations. These lookup tables are required for dose evaluation.

Routine measurement and evaluation of personnel monitoring films is being done satisfactorily since 1994 using this system. The system is easy to operate with improved efficiency and reliability thereby reducing time, cost and manual errors involved.

4. CALIBRATION OF DOSIMETERS

The response of the personnel monitoring Agfa-Gevaert film packs (photographic film dose meter) exposed to ionizing radiation, is dependent on the type of radiation to which they are exposed and also the response is non-linear to the quantity of the radiation (figure-2). The personnel monitoring film packs, therefore, require calibration to various radiations of different energies and amount of exposures ranging from possible lowest to the highest. Personnel monitoring films are calibrated for X-rays, Gamma rays and Beta radiation.

Beta rays: Beta calibration is carried out, once in a month, using natural Uranium semi-infinite flat disc sources for all the 25 batches that are processed in a month.

X-rays: X-ray calibrations are carried out for each batch of 500 packets of films using X-ray energies shown in table-I.

Gamma rays: Routine Gamma calibrations are carried out using Ra^{226} gamma ray source in radioactive equilibrium (effective energy 0.8MeV) for each batch of nearly 500 film packs processed every month. Since nearly 25 batches are processed each month, 25 sets of films are calibrated routinely using Ra^{226} gamma ray source. Occasionally Co^{60} (Teletherapy), Ir^{192} and Cs^{137} gamma rays are also used, as and when the emulsion number changes.

Whenever a new batch of film packets is received, calibration is done for all the X-ray energies mentioned above. Whenever film packs of different emulsion are received, 2 sets of calibration are done for 100 KVp X-rays and Ra^{226} gamma rays. If these calibrations are found to be in agreement with the currently being used ones, within ±10%, no further calibration is done and the current values are being used.

However the gamma and beta calibration are done routinely. It is proposed to switch over to Cs^{137} gamma source instead of Ra^{226}.

4.1. BETA CALIBRATION

The personnel monitoring film packs are exposed to beta radiation with the help of natural uranium semi-infinite discs. Sensitive side of the film packs are kept on the surface of the natural uranium disk (estimated surface dose 2.40 mGy per hour exposure) for various predetermined time duration. The time duration for various beta exposure doses is given in the table-II.

4.2. X-RAY CALIBRATION

X-ray machine is adjusted such that the centre of its beam is horizontal and at a height of more than 1.0 meter from the floor and more than 1.3 meters from the nearest wall. A 30cm * 30cm * 15cm IAEA PMMA phantom is kept on a wooden stool at a distance of more than 3.0 meter from the target of X-ray machine and its front surface atleast 1.30 meters away from the nearest wall. The centres of the front surface of the phantom and X-ray machine, being at the same height, are aligned horizontally with the help of narrow red laser beam. After aligning the centre, the phantom is replaced with ionization chamber and its sensitive air volume is aligned to that of phantom.

The X-ray machine is switched on, introducing necessary filters and consistency of values of exposure and time is ascertained. The phantom is then placed once again at the earlier position and exposures are repeated, keeping ionization chamber at various positions on the front surface of the phantom to map the area for the uniformity of the exposure. Once the area is marked the film packs are loaded in chest holder and are fixed with help of cello tape. These films are exposed to radiation doses from 0.1 mSv to 1 Sv (10 mR to 100R). This procedure is repeated for all energies of X-rays (KVp's). Necessary correction in the exposure values is incorporated for atmospheric pressure and temperature of the X-ray room. These are further multiplied by a factor of 0.87 to achieve

Air Kerma values and then by Hp/Air Kerma ratios appropriate to the energies of X-rays to get Hp values in mSv.

4.3. GAMMA CALIBRATION

A 250 mCi Ra^{226} (in equilibrium) source is used for the routine calibration of the personnel monitoring films. Film packs are loaded in chest film holder and kept at different predetermined distances from the centre of the source on curved Aluminum stadium with the help of the strips of various predetermined radius of curvatures at different elevations such that none of them shields the other. The distances of the strips are so adjusted that for the same time of exposure, the films are exposed to different predetermined values of exposures. Since the strips used in stadium are very thin and interspace is filled with air only, the back scattering contribution of radiation is ignored. The distance & time duration for various gamma exposure doses is given in the table-III below.

Routine calibration is done for doses upto 33.5 mSv (3350 mRem). Normally gamma calibration is done at the time when the films are dispatched for use to different institutions and these calibration films are included in each batch of used films.

In addition to normal routine calibration, personnel monitoring films are calibrated up to 10 Sv of gamma rays with the help of 250 mCi Ra^{226} once a new batch of 500 packets is received.

5. DOSE EVALUATION

Personnel monitoring devices are used for the occupational dose measurements. Each occupational worker is issued a film dosimeter for the monitoring period of one month and is required to wear the dosimeter whenever he enters the radiation areas. These films are loaded in a six-window multifilter chest film holder described earlier.

The doses are evaluated with the help of calibration graphs generated by exposing the films to the known doses and drawing the appropriate H&D curves for respective type of radiation. The determination of the incident energy, in case of X-rays, is done by referring the curves drawn between net optical density v/s log exposure and comparing the attenuation of radiation under various metallic filters, for the various energies of X-rays. Similarly beta energy can be determined from the difference between open and plastic windows. The determination of energy of incident radiation is essential, as the sensitivity at 40KeV is 22 times greater than that at 250 KeV (Figure 3). The typical characteristic curve (H&D curve) for X, beta and gamma are also given in figures 3-7.

If the dosimeter used by a person records dose in excess of 10 mSv during the monitoring period, it is called overexposure. These exposures are unusual and probability of such occurrences is quite limited. The probable causes of these overexposures are thoroughly investigated by the physicist/R.S.O. of the institution. In case of radiation workers receiving dose ≥ 10 mSv, the report, dosimetric data, hematological reports and results of C.A. tests are put up before an Overexposure Investigation Committee appointed by Director, Bhabha Atomic Research Centre which decides whether an overexposure is genuine or not. The film badge has a definite advantage in deciding the genuineness of a particular overexposure from the pattern on the film.

6. FADING STUDIES

Fading studies were undertaken to evaluate the suitability of the personnel monitoring film with a view to eliminate any error in evaluation of doses over a period. This becomes all the more important due the fact that the film dosemeter has a fading tendency during high humidity.

A 250 mci Ra^{226} (in equilibrium with its daughter products) was used as the gamma radiation source. For the study of film, only gamma radiation exposures were carried out. The films were exposed to radiation after loading them in PMS (erstwhile DRP) chest film holders containing various metallic filters. The films were exposed to various exposures from 0.2 mSv to 1 Sv (20mR to 100 R) of gamma radiation in free air. The exposed films were processed as per the standard procedure in vogue in our laboratory.

For studying the latent image fading different sets of films loaded in chest film holders were exposed to various doses of gamma radiation. One set (control\reference set) was processed without delay after the exposures and the other sets were stored in specially designed humidity boxes containing saturated solutions of KNO_3 water solution in petridishes to get the desired R.H level of 95% at 30 degree centigrade and were kept in incubator, temperature of 30 degree centigrade was maintained through out and these films were processed after one week, two weeks, four weeks and six weeks. Another set was exposed and kept in ambient condition in our laboratory. The temperature and relative humidity were checked and noted thrice in a day during the period of measurement. The relative humidity varied from 83% to 86% and temperature varied from 25 degree to 26 degree centigrade. These sets were processed after one week, two weeks and four weeks.

Optical density readings were measured on calibrated optical densitometer. Graphs were drawn for optical density v\s exposure values were plotted in semilog as well as linear graph papers. The graph were drawn both for fast and slow emulsions. The studies on the personnel monitoring film packs show that their dosimetric characteristics are adequate for radiation exposures and the film can be easily used for a period of one month. It is also confirmed that the fading is well within the limit stipulated.

7. DOSE DISTRIBUTION

In the present analysis, the dose per year per person is analyzed for the five-year period from 1994 to 1998. As per AERB directive the cumulative dose for the block year 1994 to 1998 should not exceed 100 mSv and in any single year effective dose should not exceed 30 mSv. During the five years block 13312 medical radiation workers in 1416 institutions and 3541 industrial radiation workers in 297 institution were monitored for external radiation. Table-IV gives the doses accumulated by occupational radiation workers during radiation work in medical and industrial institutions.

This analysis gives the complete picture of the doses accumulated per person for the block of five years including the excessive exposure doses by occupational radiation workers in medical and industrial institutions. It can be seen that the average cumulative dose per person is minimal and contribution of overexposure cases to per capita dose is not significant in the block year 1994-1998. It is observed that average dose received for industrial institutions is 1.59 mSv while it is 1.76 mSv for workers in medical institutions in the same period. It is also observed that more than 32.4% of persons have received zero doses while 96.7% radiation workers have received doses below 10 mSv during the block of five years 1994 to 1998. Also 98.7% of the radiation workers have accumulated doses below 20 mSv during the same block of five years.

The average annual dose per person during a particular year from 1994 to 1998 has been arrived at by dividing the total dose accumulated by all the radiation workers with the total number of radiation workers in that category. Table-V summarizes the number of radiation workers exposed to different dose levels and the average dose. The average annual doses received during the year for medical category have been found to be in the range of 0.4 mSv to 0.8 mSv and for industrial category the average doses are in the range of 0.4 mSv to 0.7 for the years 1994 to 1998. These values are much below the stipulated annual equivalent dose limits and are comparable to the overall average values for all the radiation workers monitored from these medical and industrial institutions in the country. The comparison of average doses received during the year for both categories (medical as well as industrial) and combined is also given in figure-2. Average dose figure has more or less remained well below stipulated limits. Table-VI shows the combined average dose distribution of doses received by all radiation workers throughout the country, using both Film & TLD monitoring dosemeters in industrial & medical categories of institutions during the block year 1994 – 1998.

It is evident from table-VII that during particular year in a block of five years (i.e. 1994 to 1998) less than 98% of the radiation workers have received doses 10 mSv or less. Also 98.6% of the radiation workers accumulated doses below 20 mSv during the same block of five years 1994 to 1998. This confirms that the doses received by the radiation workers in the categories of medical as well as industrial are well below the stipulated limits.

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LIST OF TABLES

Table-I: X-ray energies used for calibration

KVp	Filtration	Eff. Energy(KeV)
Diagnostic X-rays		
40	3mm Al	25. 4
60	3mm Al	30. 4
80	3mm Al	34. 2
Deep Therapy X-rays		
75	2mm Al	32
100	0. 2mm Cu	46
150	0. 35mm Cu	58
200	0. 5mm Cu	78
250	1. 0mm Cu	108

Table-II : Exposure table for beta radiation Natural Uranium

Time	Exposures (mSv)
5 min.	0.2
10 min.	0.4
20 min.	0.8
25 min.	1.0
50 min.	2.0
1 hr. 40 min.	4.0
3 hr. 20 min.	8.0
5 hr.	12.0
10 hr.	24.0
12 hr. 30 min.	30.0
20 hr. 50 min.	50.0

Table-III : Exposure table for gamma radiation Ra^{226} 100 mCi

Distance (cms)	Time (Hrs.)	Exposures (mSv)
141. 6	0. 5	0.2
101. 1	0. 5	0.4
71. 8	0. 5	0.8
141. 6	2. 5	1.0
101. 1	2. 5	2.0
71. 8	2. 5	4.0
51. 0	2. 5	8.0
41.2	2.5	1.2
35.8	2.5	1.6
24.8	2.5	33.5

Table-IV: Cumulative doses received during the block period 1994 to 1998.

Year	Category	No of Radiation Workers for Doses (mSv)								Total No. of Radiation Workers monitored	Average Cumulative Dose (mSv)
1994 to 1998		0	>0 to 10	>10 to 20	>20 to 40	>40 to 60	>60 to 80	>80 to 100	>100		
	Industrial	1571	1866	65	27	4	2	2	4	3541	1.59
	Medical	3886	8970	271	38	8	5	5	10	13312	1.76
	Total	5457	10836	336	42	10	7	7	14	16853	1.72

Table-V: Year-wise distribution of doses received by radiation workers in various dose ranges for year 1994 – 1998

Year	Category	No of Radiation Workers for Doses (mSv)							Total No. of Radiation Workers	Average Dose (mSv)
		0	>0 to 5	>5 to 10	>10 to 20	>20 to 30	>30 to 100	>100		
1994	Industrial	1417	615	29	16	2	1	1	2081	0.54
	Medical	3771	3454	77	33	4	3	0	7342	0.41
	Total	5188	4069	106	49	6	4	1	9423	0.44
1995	Industrial	1466	740	22	4	4	1	0	2237	0.40
	Medical	3407	4259	103	42	18	24	1	7854	0.74
	Total	4873	4999	125	46	22	25	1	10091	0.67
1996	Industrial	1411	699	20	11	0	2	3	2146	0.68
	Medical	3661	4199	90	28	11	11	1	8001	0.54
	Total	5072	4898	110	39	11	13	4	10147	0.57
1997	Industrial	1327	798	34	9	3	2	0	2173	0.47
	Medical	3489	4566	72	37	6	11	1	8182	0.53
	Total	4816	5364	106	46	9	13	1	10355	0.51
1998	Industrial	1181	963	21	6	1	4	0	2176	0.53
	Medical	2753	4466	86	42	10	9	6	7372	0.81
	Total	3934	5429	107	48	11	13	6	9548	0.74

Table–VI: Percentage of radiation workers receiving doses less than 10 mSv.

Year	No of Radiation Workers	%
1994	9257	98.2
1995	9872	97.8
1996	9970	98.2
1997	10180	98.3
1998	9363	98.0

Table–VII: Radiation workers monitored in all medical and industrial institutions and their average doses year wise

Year	Category	No. of Workers	Average Doses (mSv)
1994	Industrial	5209	1.15
	Medical	14229	0.53
	Total	19438	0.69
1995	Industrial	5625	0.96
	Medical	15759	0.60
	Total	21384	0.69
1996	Industrial	5371	0.96
	Medical	16087	0.46
	Total	21458	0.59
1997	Industrial	5440	0.82
	Medical	15763	0.51
	Total	21203	0.59
1998	Industrial	5468	0.74
	Medical	14503	0.62
	Total	19971	0.65

LIST OF FIGURES

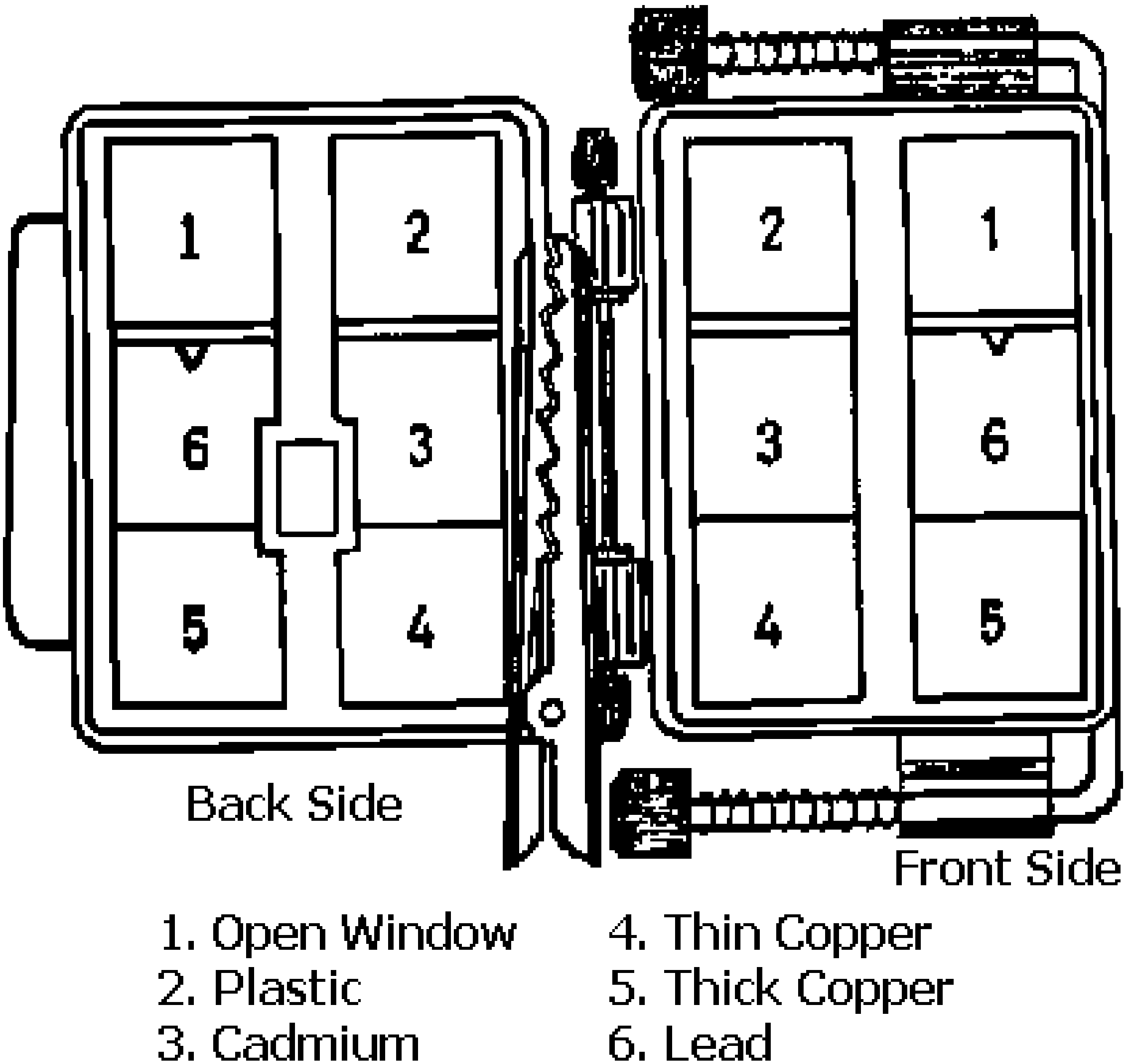

Figure-1: Chest Film Holder

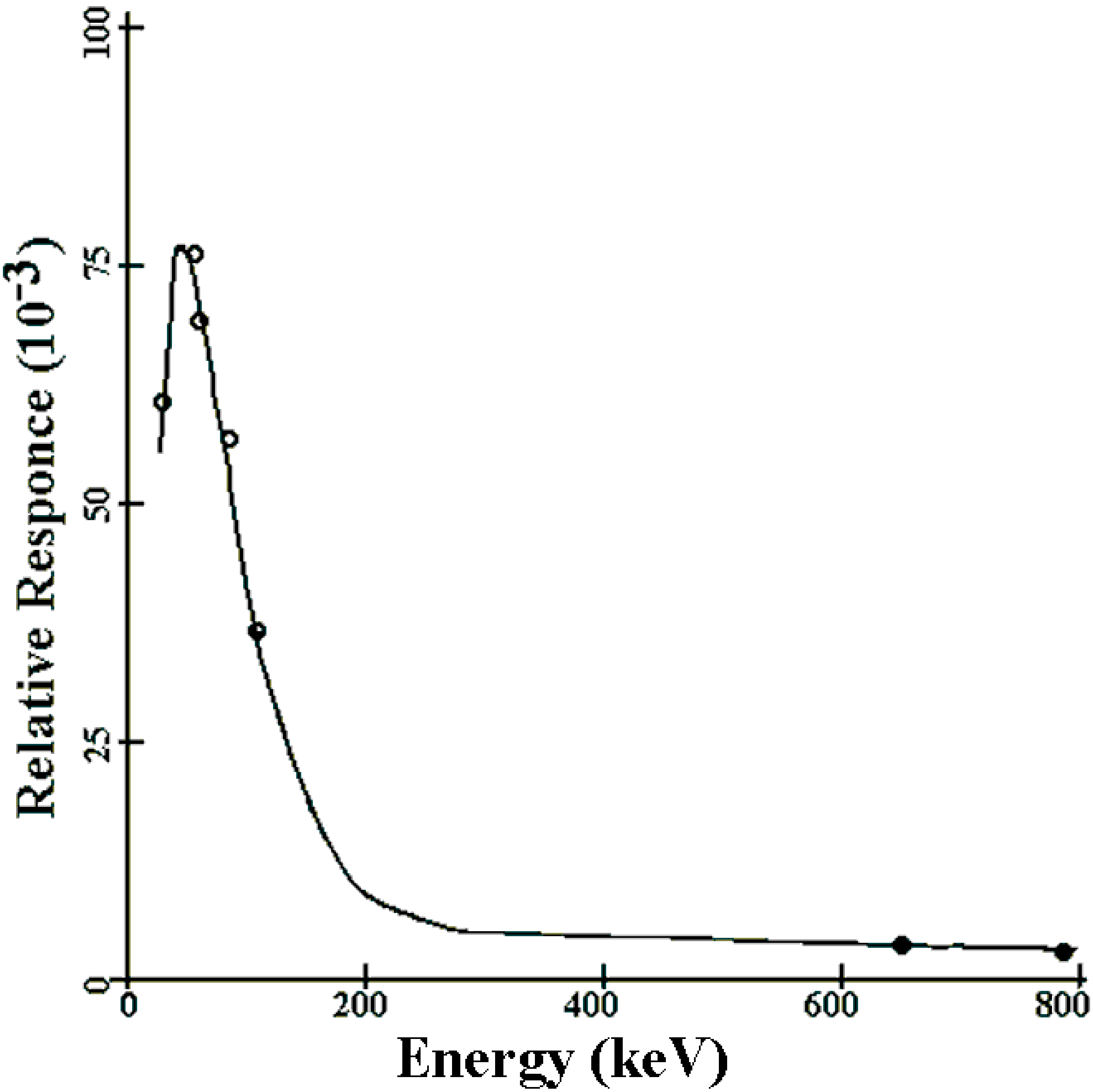

Figure-2 : Energy response of Personnel Monitoring film (Normal Incidence)

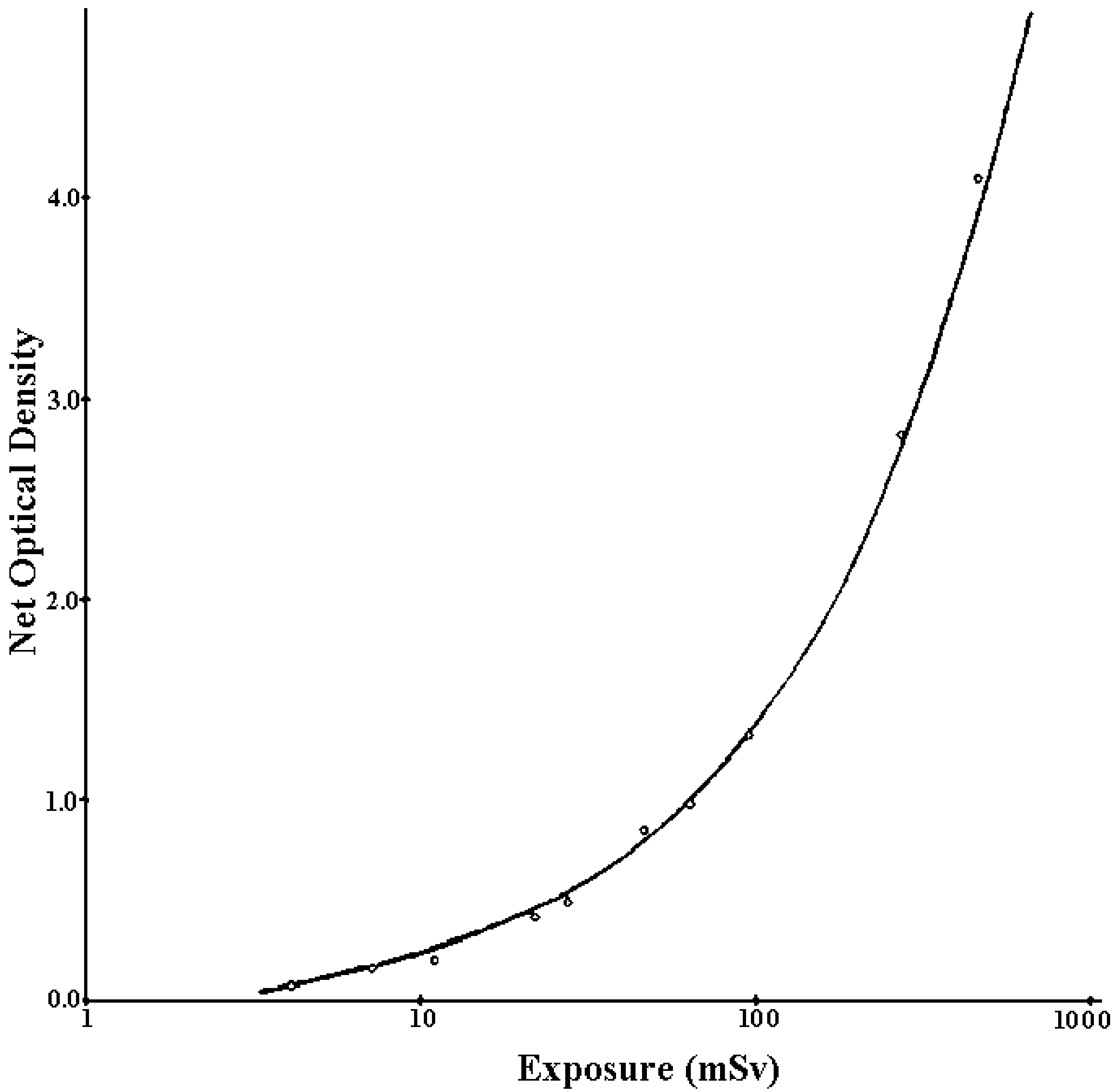

Figure-3 : Density vs Log Exposure curve for Beta rays (Slow emulsion - Agfa-Gevaert film)

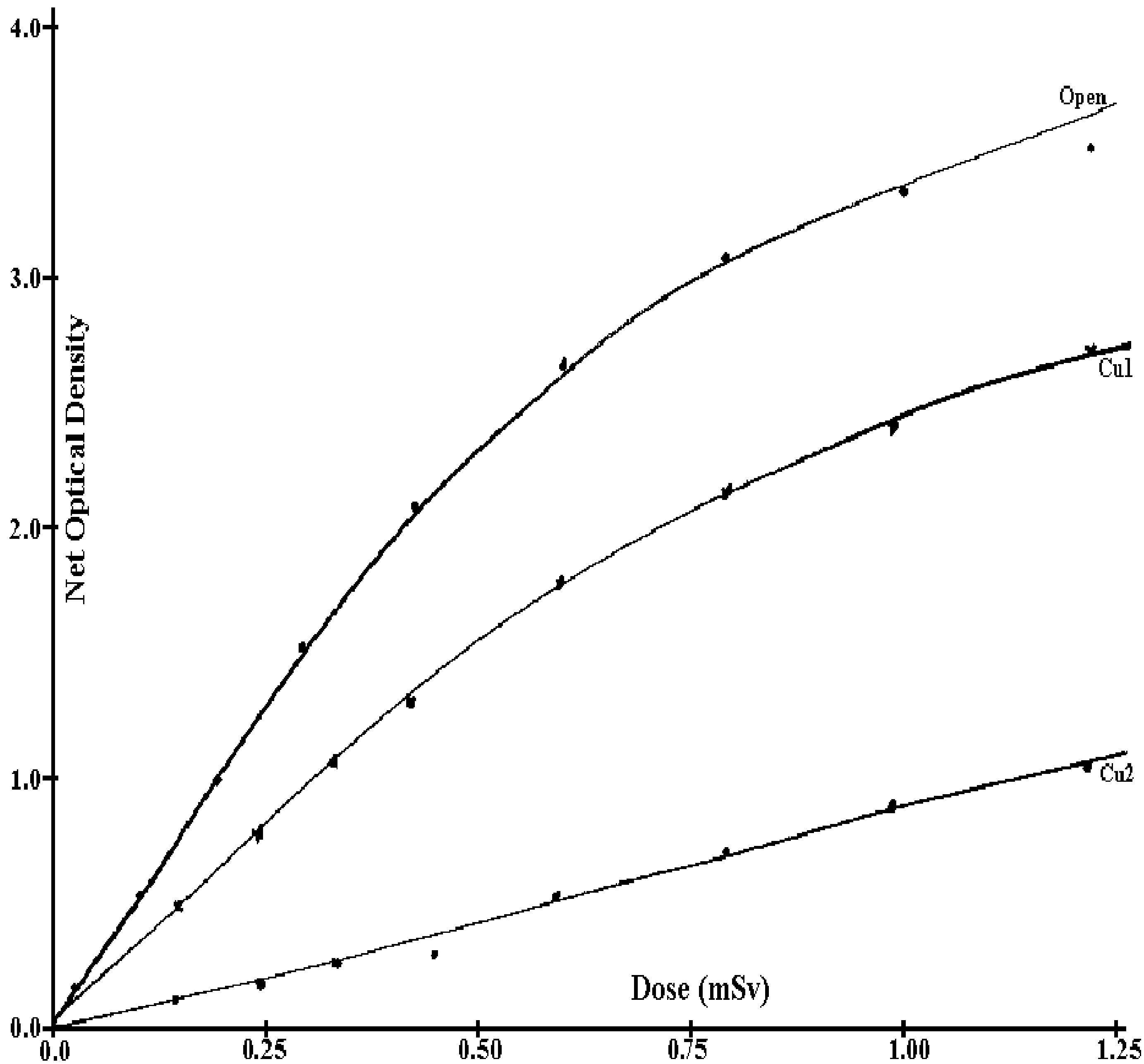

Figure-4 : Density vs Log(Exposure) curve for 100 KVp X-rays (Fast emulsion - Agfa-Gevaert film)

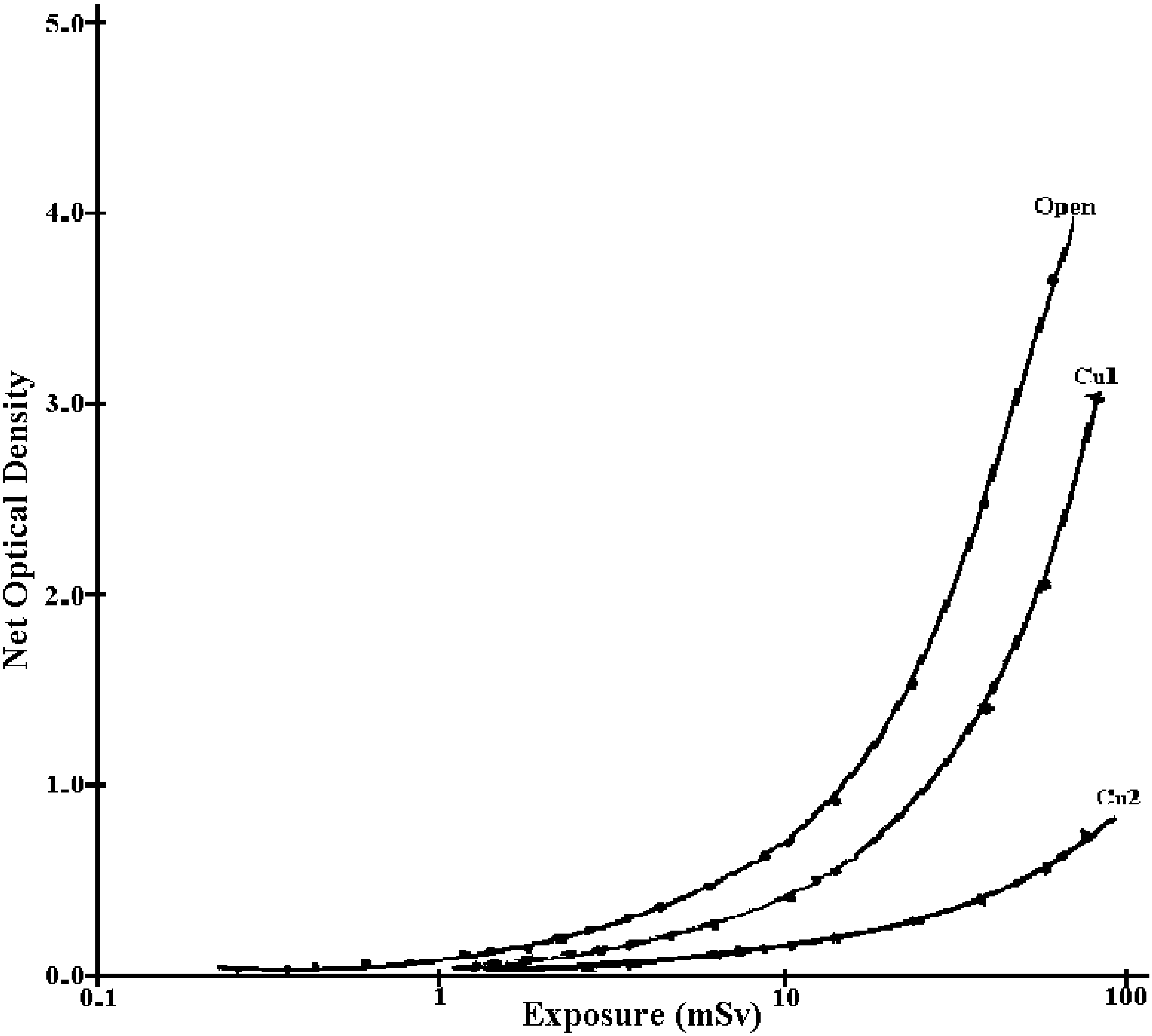

Figure-5 : Density vs Log(Exposure) curve for 100 KVp X-rays (Slow emulsion - Agfa-Gevaert film)

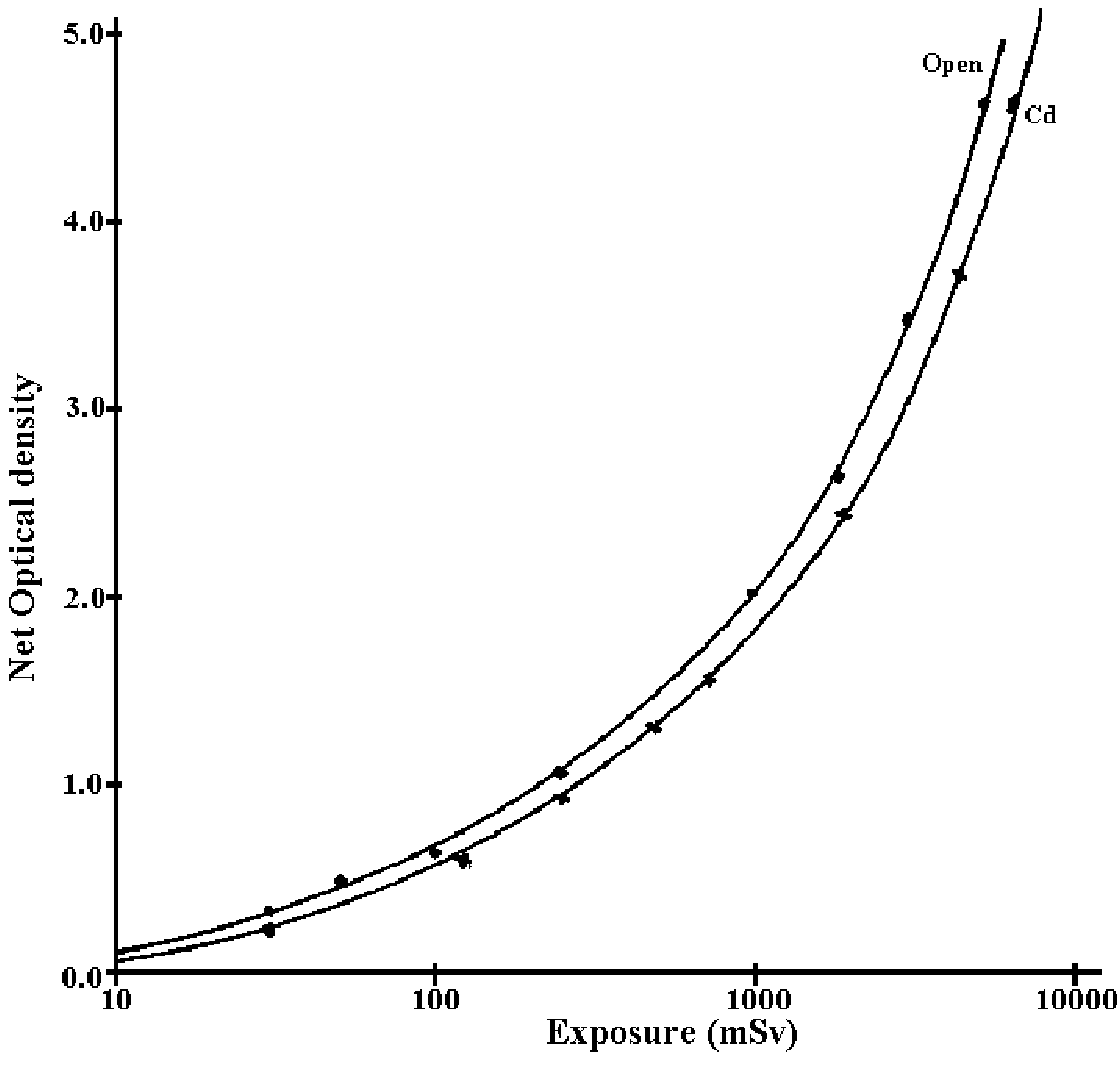

Figure-6 : Density vs Log(Exposure) curve for Gamma rays (Slow emulsion - Agfa-Gevaert film)

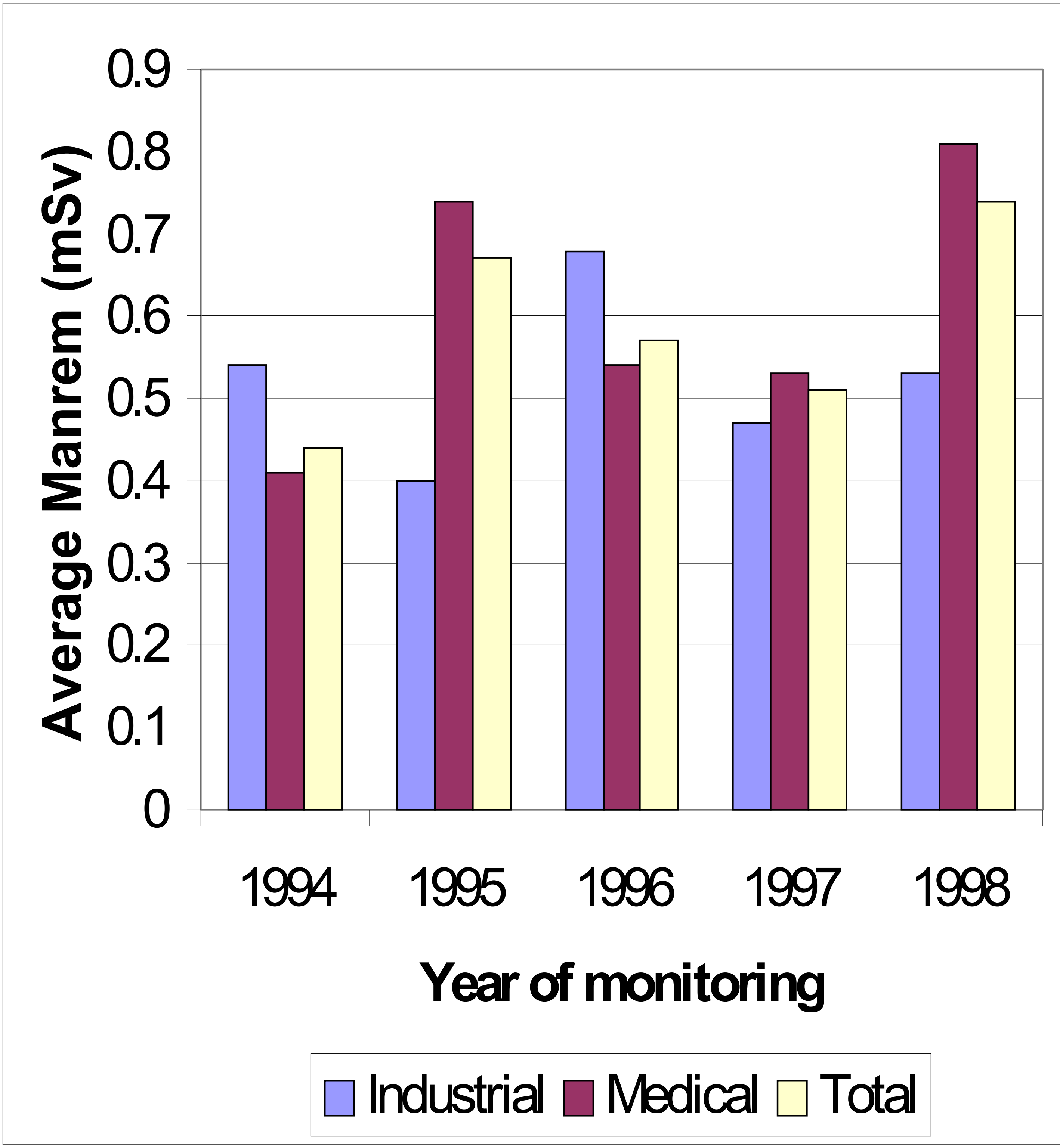

Figure-7 Average annual radiation doses received in institutions covered under Film Badge Service