A THREE-YEAR SURVEY OF FILM BADGE SERVICE PERFORMANCE IN IRAN

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ABSTRACT

An extensive study was undertaken to investigate on the overall film badge service performance with which occupational radiation exposures are reported in Iran. The study involved the analysis of film badges exposed to x-and gamma rays and beta particles. For test exposures, x-rays between 60 and 140 kV_p, Co-60 gamma radiation and Sr-90 beta particles were used. The actual delivered dose equivalents were limited to 0.40-5 mSv which is the range of annual occupational dose reported by many international studies. This study revealed that the reporting on gamma rays, specially for Co-60, was very good. The reports on x-rays were overestimated. The overestimation was considerable at higher kV_p's. The results for beta particles were rather poor.

Key words: low level radiation; film badge dosimetry; occupational radiation exposure

INTRODUCTIOIN

Photographic film is widely used for personnel monitoring in Iran. The film badge dosimetry in the country is provided by the Film Badge Services Divison under the Atomic Energy Organization of Iran, which is referred to as the contractor.

The unirradiated film badges are sent out by the contractor to all the users, on a monthly basis. The requisite number of films is accompanied by one control film to monitor background and enviromental effects. The contractor, after receiving the used films, takes usually about a month to report on the dosimetry results. This extensive study was undertaken at Shiraz University in response to a general concern about the accuracy with which radiation exposures are reported by the contractor.

The present work is concerned with the analysis of the exposure reports of x-and γ-radiations and beta particles, as they constitute the major sources for film badge service in this country.

This investigation was limited to low level radiation as there is a growing universal concern over the possible biological effects at low doses (1). Further, the prior studies (2) indicate that the average monthly dose equivalents reported in 1978 for 1,470 Iranian radiology workers, were 99.63% under 4 mSv (400 mrem), and 98.5% under 1.25 mSv (125 mrem). Other independent studies carried out in the U.S. (3), in Kuwait, (4) and in Taiwan (5,6), also the work done in France (1975), United Kingdom (1981), Canada (1974) and Australia (1975) (7) all ascertian comparable annual occupational exposure levels.

MATERIALS AND METHODS

The type of personal monitoring film used in Iran is usually Eastman Kodak Type 2[a] (and occasionally Agfa-Gevaert[b]) which consists of gelatin and silver bromide (AgBr) applied to a supporting base of cellulose triacetate or polyester. The size of the silver bromide grains is about 1 micron in diameter. The film is held inside a RPS/AERE holder[c].

During a 3-year (consecutive) period a total of 429 pieces of film badge were exposed to the known amounts of x-or γ-radiations and beta particles ranging from 0.04 mSv (4mrem) to 5 mSv (500 mrem). Exposures of mixed radiations were avoided to alleviate the complexity of superimposition of different radiation components. The summary of the irradiation conditions of the film badges is provided in Table 1. The temperature and humidity during irradiation varied yearly between -0.4C to 37.3C and 24.5% to 63.5%, respectively.

The exposed films were then sent back to the contractor each month for evaluation. The exposure reports, upon receipt, were checked agianst the delivered dose equivalents and the data were compiled. The film badges selected for irradiation were unspecified ones so that no dose was recorded against any user. To check the accuracy of our irradiation condition, the World Health Organization Regional Reference Center for secondary standard radiation dosimetry in Iran was also asked to irradiate a number of films used in the study. The contractor apparently was unaware of the study expcept for the 182 pieces of film badge that were called "experimental". For the experimental film badges,the contractor had no initial knowledge of the source or amount of radiation delivered. The following month, the type and quality of the radiations were discolsed for the 100 experimental films, while information on the ture amounts of the delivered exposures was withheld to determine if the new disclosure affected the expousre re-evaluation. In the first case, the dosimetry report received from the contractor was called the FIRST REPORT and in the latter, the SECOND REPORT.

The sources used in the study included Sr-90[d],Cs-137[e], and Co-60[f] (all standard sources) and typical medical diagnostic x-ray machines[g]. Digital dosimeters[h] were utilized to determine the true amount of doses delivered by the selected radiation sources. The sensitivity of the digital dosimeters was ± 1%.

Since the contractor repored dose

[a] Eastman Kodak, 7000-Stuttgart-60, P.O. Box. 369, W. Germany and Kodak (NEAR EAST) INC., P.O. BOX 11460, Dubai.

[b] Agfa-Gevaert NV, Septestraat 27, Belgien-2510.

[c] Radiological Protection Service and the Atomic Energy Research Establishment in Great Britain, Type E.R.P. 30 Black Spot (5 Cm x Cm3.7 x 0.9 Cm).

[d] 33.3GBq, April 4, 1980. Type 2503.3, Ser. No. 190, PTW, Freiburg, West Germany.

[e] 4.18 TBq, July 1, 1980. Code CDC 809, Ser. No. 1959 GM, Amersham, England.

[f] 400 Ci, March 31, 1967. Ser. No. 1151, Teratron, Junior, Atomic Energy of Cananda.

[g] Siemens Stabilipan, kV_p = 60-300, mA=20; Siemnens Tridors 5S.kV_p = 35 - 125, mA = 50 - 500; Siemens Heliophos 4S, kV_p = 30-150, mA=20-500.

[h] Scatter Chamber, 600cc, Ser. No. 244, Type 2575, National Physics Laboratory, England; Normal Chamber, 0.6 cc Ser. No. 792, Type 2571, PTB, West Germany.

equivalents below 0.05 mSv as an asterisk(*), it was impossible to treat the asterisk as a specific number. Based on the previous yearly cummulative occupational expousre reports where the sum of 12 asterisks, reported for 12 months of the year,was still expressed as an asterisk and further, due to the fact that asterisk was also used by the contractor for all unexposed returned films, therefore, all asterisks were treated as zero in the figures and calculations.

RESULTS AND DISCUSSION

For easy reference, the entire irradiation conditions were grouped into 8 cases and summarized in Table 1. Each case is discussed separately. To analyze data in each group a regression analysis technique was utilized (8). The model used was

$$\hat{y} = \bar{y} + b\,(x-\bar{x}),$$

where

y = the forecasted or smoothed value of reported dose equivalent
x = the actual dose equivalent
$\bar{x}$ and $\bar{y}$ = the mean of the actual and reported dose equivalents, respectively
b = the slope of the regression line, which is the best linear curve that fits the data

Case No. 1

A total of 239 film badges were irradiated by Cs-137 γ-rays ranging from 0.04 to 5 mSv. The best regression line was calculated to be

$$\hat{y} = 67.96 + 1.09\,(x - 67.53)$$
$$\text{for } 6 \le x \le 500, \quad r = 0.97.$$

Although the actual dose equivalent was slightly overestimated, the coefficient of correlation was 0.97. The actual dose

Table 1. Summary of film badge irradiation conditions.

Radiation	kV_p (Added filter) or source	Irradiation range (mSv)	Number of films irradiated (N=429)
x-ray	60 (1 mm A1)	0.25-0.88	10
x-ray	70 (1 mm A1)	0.04-0.70	47
x-ray	80 (1 mm A1)	0.10-2.17	39
x-ray	100 (2 mm A1)	0.5-0.96	20
x-ray	140 (2 mm A1)	0.13-0.96	24
Gamma	Co-60	0.05-4.86	20
	Cs-137	0.04-5.00	239
Beta	Sr-90	0.07-4.84	30

equivalent was underestimated for dose equivalents less than 0.3 mSv (30 mrem) and overestimated for dose equivalents greater than 0.3 mSv as compared to the total average of the reported dose equivalents. Because of the significant differnece between the reported and actual dose equivalents below 0.3 mSv, the data were divided into two groups as follows:

(a) For actual dose equivalents below 0.3 mSv, the data show that the reported value is either zero or at most one-half the actual dose equivalent. Because of the insufficient data no regression line was drawn.

(b) For acutual dose equivalents above 0.3 mSv, the regression line was claculated as

$$\hat{y} = 138.23 + 1.06\ (x - 126.41)$$
$$\text{for } 30 \leq x \leq\ < 500,\quad r = 0.97.$$

There also seemd to be a significant difference in the mean reported dose equivalent for each of the 3 years of the study. The regression lines otained for each year separately were

First year

$$\hat{y} = 13.30 + 1.08\ (x-24)$$
$$\text{for } 12 \leq x \leq 70,\quad r = 0.91;$$

Second year

$$\hat{y} = 22.30 + 1.29\ (x-26)$$
$$\text{for } 9 \leq x \leq 70,\quad r = 0.82;$$

Third year

$$\hat{y} = 137.0 + 1.05\ (x-125)$$
$$\text{for } 4 \leq x \leq 500,\quad r = 0.82.$$

For the first year, the actual dose equivalent was underestimated, whereas for the third year, it was overestimated and the reported dose equivalent for the second year was somewhere between the two.

Case No. 2

Twenty film badges were irradiated by Co-60 γ-rays ranging from 0.5 to 4.86 mSv. Except for three film badges, the FIRST and SECOND REPORTS were identical. That is, prior knowledge of the source did not influence the dosimetry report for Co-60. The best regression line was claculated to be

$$\hat{y} = 181.20 + 1.00\ (x-172.4)$$
$$\text{for } 5 \leq x \leq 500,\quad r = 0.99.$$

The estimation in fact was very good for Co-60.

Case No. 3

Thirty film badges were irradiated by Sr-90 ranging from 0.07 to 4.84 mSv. The best regression line for the FIRST REPORT was

$$\hat{y} = 27.60 + 0.12\ (x-112.2)$$
$$\text{for } 19 \leq x \leq 484,\quad r = 0.70,$$

and the regression line for the SECOND REPORT was

$$\hat{y} = 224.22 + 2.40\ (x-112.20)$$
$$\text{for } 19 \leq x \leq 484,\quad r = 0.99,$$

which means that the prior knowledge of the source greatly influenced the dosimetry report for Sr-90 beta rays. In either case, the contractor seemed to be in error in reporting of Sr-90.

Case No. 4 through No. 8

A total of 140 film badges were irradiated by x-rays ranging from 0.04 to 2.17 mSv at 60, 70, 80 kV_p with 1mm Al and at 100 and 140 kV_p with 2 mm Al filteration. For 100 and 140 kV_p, as before, we arranged for the FIRST and SECOND REPORTS. Except for two measurements, both REPORTS were the same indicating that the prior knowledge of the source had no influence over the two reports regarding exposure of 100 and 140

kV_p x-ray.

The best curve fits for all x-ray exposures were calculated to be as follows:

60 kV_p
$\hat{y} = 96 + 1.35\ (x - 43.5)$
for $25 \leq x \leq 90$, $r = 0.71$;

70 kV_p
$\hat{Y} = 46.14 + 1.32\ (x-24.68)$
for $4 \leq x \leq 80$, $r = 0.79$;

80 kV_p
$\hat{y} = 82.26 + 1.66\ (x-49.03)$
for $10 \leq x \leq 217$, $r = 0.92$;

100 kV_p
$\hat{y} = 273 + 6.22\ (x-49.85)$
for $6 \leq x \leq 100$, $r = 0.86$;

140 kV_p
$\hat{y} = 162.72 + 4.28\ (x-49.69)$
for $13 \leq x \leq 100$, $r = 0.81$.

The regression lines of the above five different kV_p's are plotted in Fig. 1. Evidently, the contractor always overestimated the actual dose equivalent for all x-ray exposures and, interestingly, the rate of overestimation became considerable at higher kV_p's.

The regression lines of reported dose equivalents for all types of radiation except for x-rays were plotted in a common figure to study the relative accuracy with which the contractor had reported each case. It is evident from Fig. 2, that the reporting for Co-60 is very good as one compares the regression line to that of y = x. This suggests that Co-60 may be the sorce the contractor was using to generate the calibration curve. In fact, later this was verified to be the case. The contractor uses Co-60 and some times, Cs-137.

Figures 3 and 4 show comparison between the contractor's report and the parallel dosimetry carried out at this center on Cs-137 γ-rays and 60 kV_p x-rays. The results of dosimetry performed at this center seem to be closer to the delivered actual doses. The following relation (14) was used to calculate the x- and γ- ray doses:

$$D_{x+\gamma} = D_{Sn/Pb} + 0.111\ D_{P300} - 0.1\ D_{dural},$$

where

$D_{x+\gamma}$ = the evaluated x-and γ-ray dose equivalent;

D_{P300} = the apparent γ-ray dose equivalent beneath the 300 mg/cm^2 Plastic filter;

D_{dural} = the apparent γ-ray dose equivalent beneath the dural filter;

$D_{Sn/Pb}$ = the apparent γ-ray dose equivalent beneath Sn/Pb filter.

The above formula gives a flat response to within ± 20% for the energy range 18 keV to 1.3 MeV and assumes a shallow dose.

STATISTICS

To check the validity of the results presented in the text, some detailed statistical tests were performed. The results summarized here are only for the case of Cs-137 γ-rays which constitute the highest number of data collected during study.

(a) To check the accuracy of the estimated parameter b of the regression line, a t-distribution with N-2 degrees of freedom was employed in which N was the number of the data (239) (9). It was found that the 95% confidence interval for the slope b is

$$Pr\{\ b + t_{1/2\alpha} \frac{S_{y.x}}{S_{x.}\sqrt{N-1}} \leq b \leq b + t_{1-1/2\alpha} \frac{S_{y.x}}{S_{x.}\sqrt{N-1}}\} = (1-\alpha)\%,$$

$$Pr\ \{1.05 \leq b \leq 1.12\} = 95\%.$$

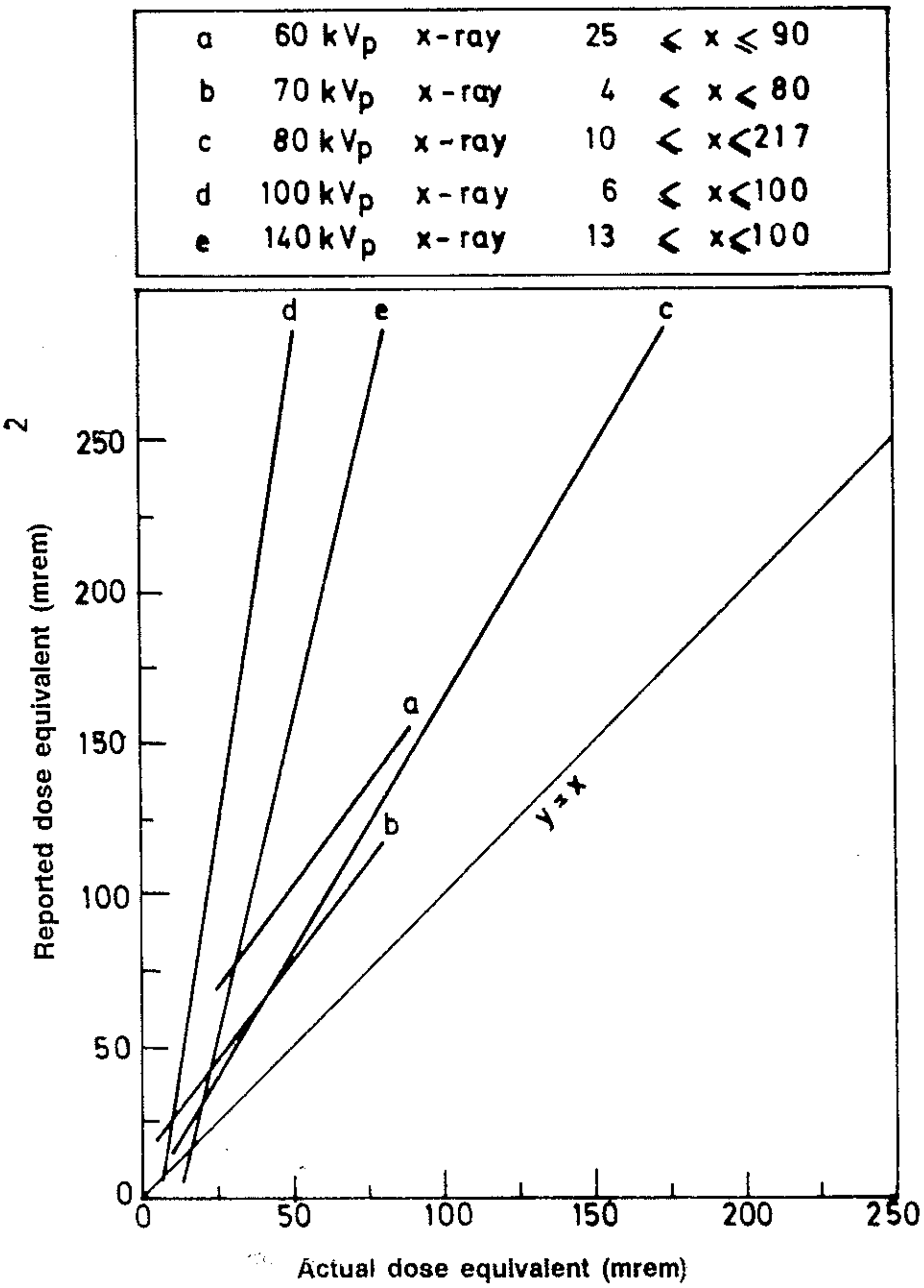

Fig. 1. Reported dose equivalent vs. actual dose equivalent for 60 kV_p, 70 kV_p, 80 kV_p, 100 kV_p, and 140 kV_p, x-rays.

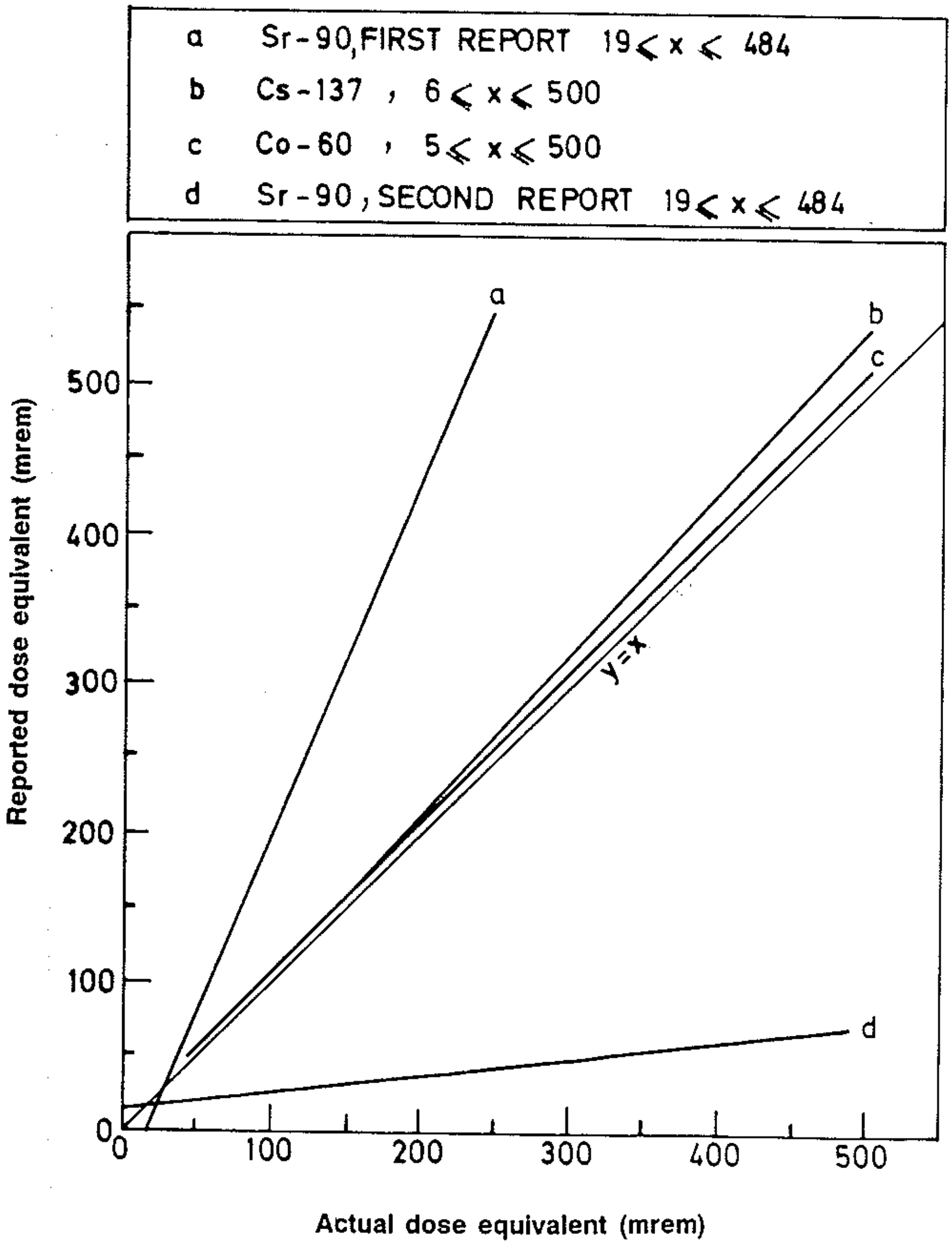

Fig. 2. Regression lines of reported dose equivalents for Co-60, Cs-137 and Sr-90 radiations compared with the line y=x.

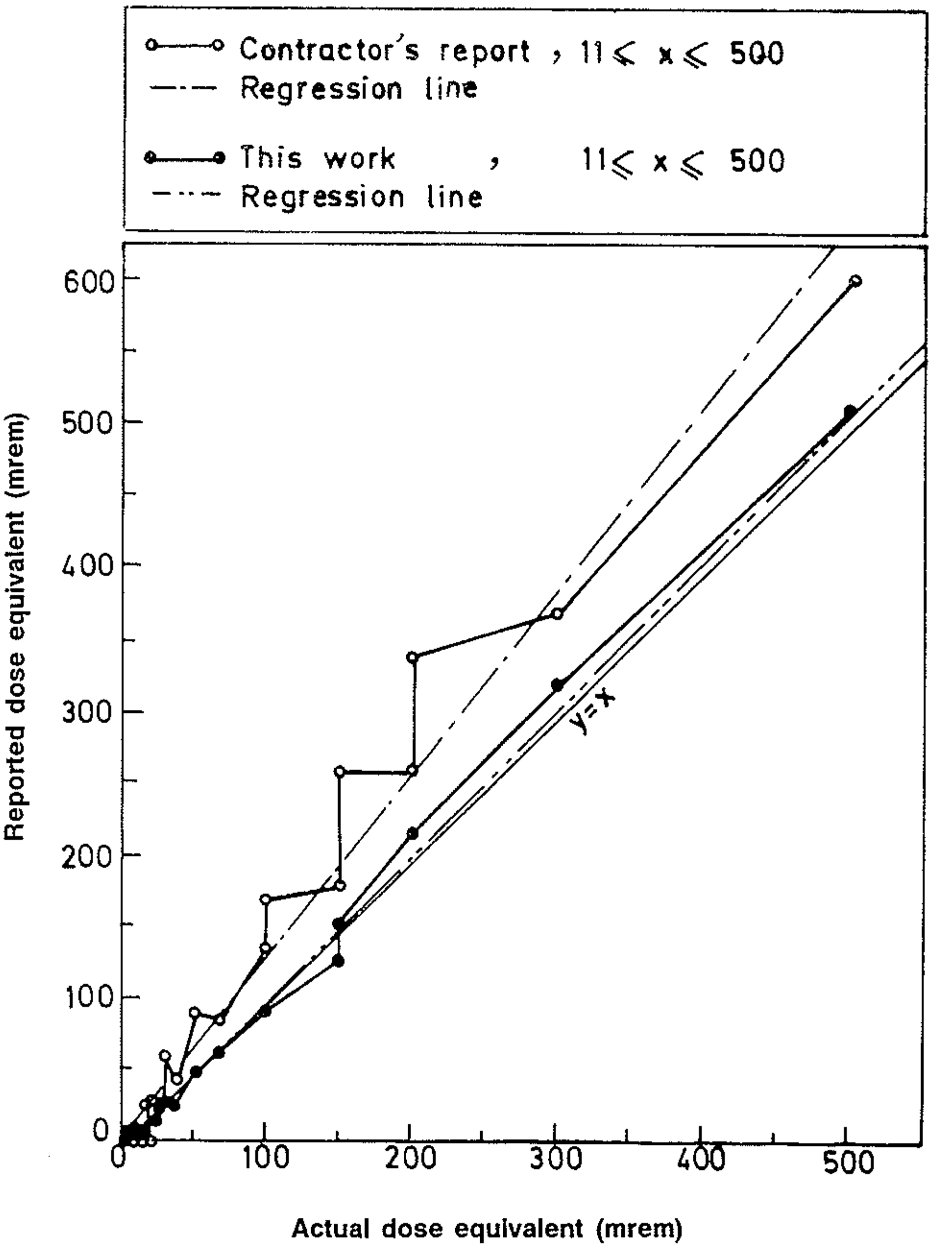

Fig. 3. Comparison between contractor's report on Cs-137 γ-ray dosimetry and this work.

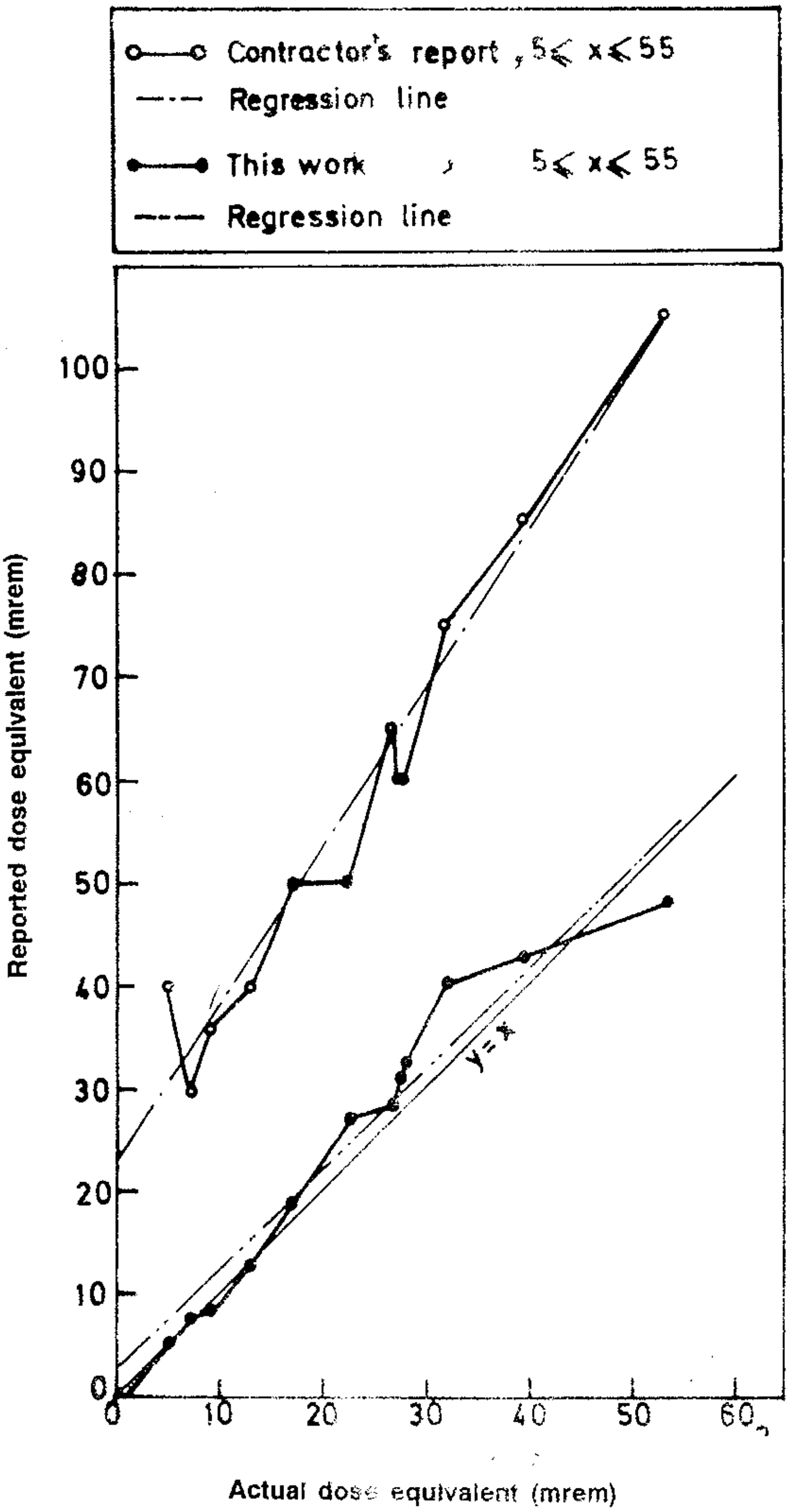

Fig. 4. Comparison between contractor's report on 60 kV_p x-ray dosimetry and this work.

That is, there is 95% confidence that the actual value for b will lie somewhere between 1.06 and 1.12, which is greather than 1, anyhow.

(b) To check the mean of the reported dose equivalent for a given actual dose equivalent, the t-distribution with N-2 degrees of freedom (11,12,13) was employed, thus,

$$\Pr\{\bar{y}_x - t_{1/2\alpha} \cdot S_{y/x} \sqrt{\frac{1}{N} + \frac{(x-\bar{x})^2}{(N-1)S_x^2}} \le \mu_{y/x} \le \bar{y}_x + t_{1/2\alpha} \cdot S_{y/x} \sqrt{\frac{1}{N} + \frac{(x-\bar{x})^2}{(N-1)S_x^2}}\} = (1-\alpha)\%,$$

where $\mu_{y/x}$ is the mean of the reported dose equivalent for a given amount of actual dose equivalent x. For instance, if the actual dose equivalent is taken to be 100 mrem, then the 95% confidence interval for the reported vlaue would be
$\Pr\{100.2 \le \mu_{y/100} \le 107.01\} = 95\%$,
which is close to 100 but greater than that.

(c) To check the dependence of y on x, a t-test was employed to check the significance of b. The test statistics $t = (b-0)\, s_x \sqrt{N-1}/S_{y.x} = 68.81$ was used, for which the rejection region was

$$t < t_{1/2\alpha},\ N\text{-}2 = -1.96 \text{ and}$$
$$t < t_{1-1/2\alpha},\ N\text{-}2 = 1.96.$$

It was conclued that there exists a significant reason to reject the hypothesis that b = 0. This means that y is certainly dependent on x.

(d) To test whether or not there exists any significant difference in the mean of the reported dose equivalent in different years, the analysis of variance was employed (12)

$$\text{test statistics } F = \frac{\text{among means, mean square}}{\text{within means, mean square}} = 2.678.$$

Comparison was made with F(K-1,N-K,1-a) where N is the number of grouped data(N=44) and K is the number of years (K=3). At 90% significance, F(2,42,90%) = 2.49, which shows that there exists a significant difference in the mean for different years. Thus, it was decided to analyze the data for each year separately.

(e) As mentioned before, there seemed to be a significant difference between the reported and actual dose aquivalents below and above 0.3 mSv. To test the mean difference between the actual and reported dose equivalent in each case, a t-test was employed (12). The data show that for dose equivalents below 0.3 mSv, the mean difference $\bar{D}$ between the actual and reported dose equivalent is

$$\bar{D} = \frac{1}{N}\Sigma D_i = \frac{1}{N}\Sigma (y_i - x_i) = -9.52$$

whereas test statistic t is

$$t = \frac{\bar{D} - 0}{S_D \sqrt{N}} = \frac{-9.52}{12.8 \sqrt{125}} = -8.31,$$

which is much greater than $t_{N-1}, 1-\alpha/2 = t_{124,0.995} \simeq 2.6$. There is a significant difference in the mean values at 0.005% and hence the actual dose equivalents are underestimated below 0.3 mSv. For higher dose equivalents, $\bar{D} = 11.83$ and $S_D = 34.26$. Thus, test statistic is

$$t = \frac{\bar{D} - 0}{S_D \sqrt{N}} = \frac{11.83}{34.26/\sqrt{109}} = 3.6$$

The comparison was with $t_{N-1}, 1-\alpha/2 = t_{108,0.995} \simeq 2.62$, and it was confirmed that there exists a significant difference in the mean of the actual and reported dose equivalent.

CONCLUSION

Steps may be taken to correct for

underestimation of γ-ray dose equivalents below 0.3 mSv. The sinsitivity could be extended by methods of optically intergrating or amplifying grain densities over a wider area of film (10). Improvements on beta and x-ray reporting, are needed. An alternative method such as TLD could be useful.

REFERENCES

1. Gofman JW. Radiation and Human Health. Sierra Club Books: San Francisco. 1981.

2. Atomic Energy Organization of Iran. Personnel Photographic Film Dosimetry in Iran: 8th Annual Radiological Congress of Iran, Isfahan. RPD-78. Conf. 17. Tehran: Nuclear Research Center Publications. 1978.

3. American Association of Physicits in Medicine. A Primer on Low-Level Ionization and its Biological Effects: AAPM Report No. 18. New York: American Institute of Physics. 1986.

4. Mustafa AA, Sabol J. and Janeczek J. Doses from Occupational Exposure: A Study of Radiation Doses to Workers in Kuwait Over a Four-Year Period. Health Phys. 49: 1197-1204; 1985.

5. Weng PS and Wang CL. An Investigation of Occupational Exposure on Taiwan (1973-1975). Health Phys. 31: 513; 1975.

6. Weng PS and Chen TC. Occupational Radiation Exposures in Taiwan (1962-1983). Health Phys. 49: 411-418; 1985.

7. United Nations Scientific Committe on the Effect of Atomic Radiation, Sources and Effects of Ionizing Radiation. New York: UN. 1977.

8. Rago CR. Linear Statistical Inference and Its Applications. John Wiley: New York. 1973.

9. Parzen E. Modern Probability Theory and Its Applications. John Wiley: New York. 1960.

10. Brownico KA. Statistical Theory and Methodology in Science and Engineering John Wiley: New York. 1960.

11. Ostle B. Statistics in Research. Iowa State University Press: Iowa 1964.

12. Dixon WJ and Massey Jr. FJ. Introduction to Statistical Analysis. MacGraw-Hill: New York. 1969.

13. Brodsky A. An Optical Device for Extending the Range of Film Measurements of γ-Radiation. Health Phys. 9: 656; 1963.

14. National Radiological Protection Board. An Evaluation of the Eastman Kodak Type 2 Film. NRPB-R130. England. 1980.