An evaluation of a dose rate parameter in occupational radiation epidemiologic studies

Taulbee TD [(1)], Spitz HB [(1)], Neton JW [(1)], and Chen PH [(1)]

[1.] *Health-Related Energy Research Branch of the United States National Institute for Occupational Safety and Health, Cincinnati, Ohio USA, email: tgt4@cdc.gov*

Introduction

Risk estimates for occupational radiation exposure are primarily based upon studies of atomic bomb survivors and other persons who received instantaneous or acute radiation exposure. In contrast, occupational radiation exposure tends to be received at a low intensity and in a fractionated or protracted manner.

Multiple studies of animals have clearly demonstrated that fractionated and low intensity exposure to gamma radiation results in a reduced rate of cancer incidence compared to acute exposures (8,5,7,2). The International Commission on Radiological Protection (ICRP) has developed the Dose and Dose Rate Effectiveness Factor (DDREF) to accommodate the observed decrease in cancer incidence associated with fractionated gamma exposures. Although the ICRP (3) recommends a value of 2 for the DDREF, they also recognize that this value is somewhat arbitrary and in need of additional validation.

The United States National Institute for Occupational Safety and Health (NIOSH) is conducting an Occupational Energy Research Program to investigate health effects in workers who are exposed to radiation. In this analysis, we compare the conventional dose rate calculation to a new method, which is shown to be a better description of the intensity (dose rate) of the cumulative dose for epidemiological studies.

Methods

Monthly radiation dosimetry records for 360 workers from a current epidemiologic study were selected for this analysis. Of these workers, two hundred and eighty-four (284) had cumulative external radiation doses greater than 0.2 mSv. Workers with very low cumulative doses less than 0.2 mSv and three accidentally exposed workers, who received doses exceeding radiation protection limits, were excluded from this analysis. Thus, dosimetry records for 281 workers were evaluated with approximately 46% having cumulative doses greater than 10 mSv.

A new computational method for dose rate analysis was developed and compared to the cumulative average dose rate, a conventional method previously used in epidemiologic studies and analysis (1,6). The cumulative average dose rate is obtained by dividing an individual's cumulative dose by the length of time from first exposure to last exposure. The new method developed for this analysis is a "Dose Weighted Average" (DWA) which weights each monthly dose rate ($\dot{D}$) according to the fractional contribution (weight) of the monthly dose to the worker's lifetime cumulative dose (Equation 1). The weight (w_D) is the monthly dose divided by the total cumulative dose. As a result, monthly doses that contribute a greater proportion to the cumulative dose are weighted greater than multiple lower monthly doses.

$$DWA = \sum_i w_{D_1}\dot{D}_1 + w_{D_2}\dot{D}_2 + w_{D_3}\dot{D}_3 + ...w_{D_i}\dot{D}_i \qquad \textit{Equation 1}$$

Assuming that workers with similar cumulative doses do not necessarily have similar dose rates, an unbiased dose rate parameter should not be correlated with cumulative dose. For both the cumulative average and dose-weighted average methods, the

Spearman Rank correlation procedure was used to determine correlation between dose rate and cumulative dose across similar dose groups.

Results

The geometric mean dose rate calculated for these 281 workers was 0.10 and 1.28 mSv per month using the cumulative average and dose weighted average methods, respectively. The difference between these dose rates arises because the cumulative average method includes dose fractionation (time between exposures) that is explicitly excluded in the dose weighted average method. Figure 1 shows the distribution of dose rates for these workers using both methods versus cumulative dose and illustrates that workers with similar cumulative doses received their doses at different rates. In general, the dose rates calculated using the dose-weighted average method exceeded the cumulated average method and varied by an order of magnitude.

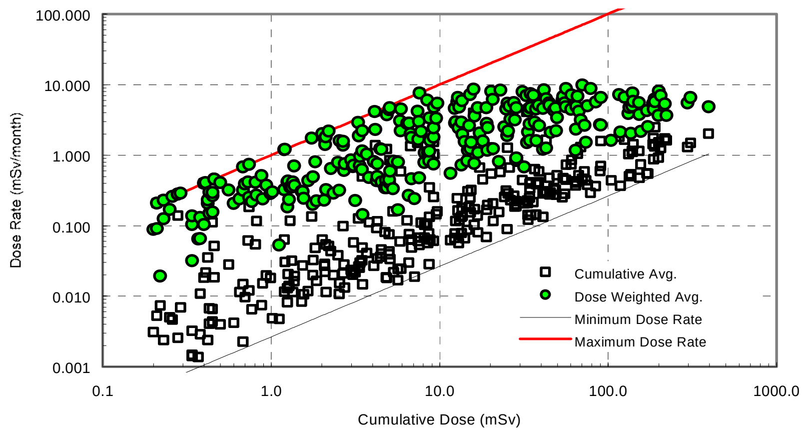

Figure 1: Comparison of the two dose rate computational methods and cumulative dose

The calculated dose rates for both methods were generally found to be log-normally distributed over most of the dataset, however, each produced a tail or compression of the log-normal distribution at the upper end. Kumazawa et al (4) noted this compression of the log-normal distribution among various radiological exposed occupations and developed a hybrid log normal distribution function to fit the data. The compression was attributed to the removal of individuals from the workplace as they approached the occupational exposure limit. While this distribution function was developed for annual dose limits, it also appears to be relevant to exposure rate limits. The effect of occupational limit was observed in Figure 1 in which workers were limited to a radiation exposure rate of 10 mSv per month.

Overall, the cumulative average dose rate method exhibited greater correlation with cumulative dose than the dose weighted average method (Figure 2). As cumulative dose increased, the cumulative average method becomes more correlated with cumulative dose. This trend would limit the utility of the cumulative average for high cumulative doses. The opposite trend was observed using the dose-weighted average, however, this method was more correlated at very low cumulative doses.

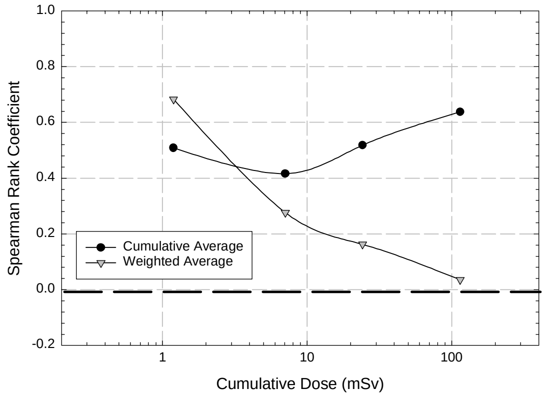

Figure 2: Correlation coefficient between dose rate and cumulative dose

Discussion

Although the cumulative average method is easy to calculate, the method results in an oversimplification that might hinder any observation of a dose rate and/or fractionation effect. Since this method combined fractionation with intensity, any potential effect of the intensity of the exposure cannot be evaluated independently. The dose weighted average method is a better relative measure of the intensity (dose rate) of exposure because it neglects periods of time between exposures. This method also puts greater emphasis on those dose rates, which are potentially more relevant to risk.

Conclusion

Currently the DDREF is used in risk estimates to account for decreased effects of radiation on human health due to fractionation and rate or intensity of exposure. In epidemiologic studies where detailed data are available, dose rate effects may be investigated. The dose-weighted average methodology discussed above was developed as a metric for these investigations. This dose rate parameter, when used in combination with cumulative dose in an epidemiologic study, might enhance our understanding of the health effects of radiation exposure and should be utilized in exposure assessments for occupational epidemiologic studies.

References

1. Blair, A. and Stewart, P. A. (1990) Correlation between Different Measures of Occupational Exposure to Formaldehyde, *American Journal of Epidemiology,* Vol. 131 (3), pp. 510.

2. Carnes, B. A. and Fritz, T. E. (1991) Responses of the Beagle to Protracted Irradiation I. Effect of Total dose and Dose Rate, *Radiation Research,* Vol. 128 (2), pp. 125.

3. ICRP, (1990), *Recommendations of the International Commission on Radiological Protection*, ICRP Publication 60, Annals of the ICRP Vol 21, Pergamon Press, Oxford, England.

4. Kumazawa, S. and Numakunai, T. (1981) A New Theoretical Analsysis of Occupational Dose Distributions Indicating the Effect of Dose Limits, *Health Physics,* Vol. 41 (3), pp. 465.

5. Storer, J. B., Serrano, L. J., Darden, E. B., Jernigan, M. C. and Ullrich, R. L. (1979) Life Shortening in RFM and BALB/c Mice as a Function of Radiation Quality, Dose, and Dose Rate, *Radiation Research*, Vol. 78 (1), pp. 122.

6. Thomas, D. C. (1990) A Model for Dose Rate and Duration of Exposure Effects in Radiation Carcinogenesis, *Environmental Health Perspectives*, Vol. 87 pp. 163.

7. Ullrich, R. L. and Storer, J. B. (1979) Influence of γ irradiation on the Development of neoplastic Disease in Mice II. Solid Tumors, *Radiation Research,* Vol. 80 (2), pp. 317. Poor Scan (microfilm original).

8. Upton, A. C., Randolph, M. L., Conklin, J. W., Kastenbaum, M. A., Slater, M., Melville, G. S., Conte, F. P. and Sproul, J. A. (1967) Late Effect of Fast Neutrons and Gamma Rays in Mice as Influenced by the Dose Rate of Irradiation: Life Shortening, *Radiation Research,* Vol. 32 pp. 493.

NR 2001:10

x2001 – Exposure Assessment in Epidemiology and Practice

Mats Hagberg, Bengt Knave, Linnéa Lillienberg and Håkan Westberg (Eds)

ARBETE OCH HÄLSA | VETENSKAPLIG SKRIFTSERIE

ISBN 91-7045-607-0 ISSN 0346-7821 http://www.niwl.se/ah/

Dept of Occupational Medicine

ICOH Industrial Hygiene

Arbetslivsinstitutet
National Institute for Working Life

National Institute for Working Life
S-112 79 Stockholm
Sweden

ISBN 91–7045–607–0
ISSN 0346–7821
http://www.niwl.se/ah/
Printed at CM Gruppen, Bromma

Preface

This book contains the extended abstracts to the X2001 Conference on Exposure Assessment in Epidemiology and Practice in Göteborg, Sweden, June 10-13, 2001. The excellent work performed by the contributing scientists has made this book a first-class, up-to-date, state of the art review on what is known about exposure assessment today.

The outstanding scientific quality of the extended abstracts was secured through the work of five international programme committees. The chairmen for the committees were: Chemical, Patricia Stewart; Ergonomic, Alex Burdorf; Physical, Ulf Bergqvist; Psychosocial, Annika Härenstam and Biological, Jean-Francois Caillard.

Financial support to the conference and thereby to the publishing of this book was made possible by contributions from The National Institute for Working Life, Stockholm, Sweden; The Swedish Council for Working Life and Social Research, Stockholm and Volvo. Without the excellent skills of the organizing committee - Ulrika Agby (administration and layout), Ann-Sofie Liljenskog Hill (administration) and Christina Lindström Svensson (administration) - the production of this book would not have been possible.

We want to express our gratitude to the contributing authors, session chairmen and to the participants who presented papers and contributed in the discussions, for making X2001 an outstanding meeting.

Göteborg in June 2001

Mats Hagberg
Department of Occupational Medicin
Göteborg University, Göteborg

Bengt Knave
The National Institute for Working Life
Stockholm

Linnéa Lillienberg
Occupational and Environmental Medicine
Sahlgrenska University Hospital, Göteborg

Håkan Westberg
Occupational and Environmental Medicine
Örebro Regional Hospital, Örebro