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A METHOD FOR DETERMINING ORGAN DOSE FROM EXTERNAL EXPOSURE MONITORING DATA

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Abstract

To estimate the probability of causation in an occupational radiation exposure compensation program, it is necessary to reconstruct the dose for the tissue or organ that was diagnosed with a primary cancer. In occupational monitoring programs, dosimeter badges are commonly used to assess compliance with prescribed exposure limits. Because the dosimeter badges measure the dose delivered at a specific point on the body, and not to the actual organ, a method has been developed to convert the regulatory compliance dose (monitored dose) to a dose to the affected organ or tissue. The method takes into consideration: 1) the response of the monitoring device; 2) the exposure photon energy; and, 2) the exposure geometry. The combination of these three factors results in a time, facility, and task specific organ dose conversion factor (DCF). This paper describes the technical approach used in developing these organ specific dose conversion factors. Examples of the relative importance of accounting for differences between regulatory compliance dose and the organ dose are provided for selected exposure conditions.

1. Introduction

Under the U.S. Energy Employees Occupational Illness Compensation Program Act [1], the National Institute for Occupational Safety and Health (NIOSH) is tasked with reconstructing internal and external organ doses for certain U.S. Department of Energy (DOE) facility workers who are covered under the provisions of the Act. Since most historical radiation monitoring data has been performed for regulatory compliance purposes, NIOSH has evaluated the applicability of compliance based external dose monitoring results against the needs of a worker compensation program that uses probability of causation as the deciding factor.

A review of the literature indicates that early external dosimetry monitoring data was based on a measure of radiation exposure in Roengten (R). More recently the ambient dose equivalent ($H^*(10)$) or the personal deep dose equivalent ($H_p(10)$) have been used to represent the external dose to a worker. Each of these values, however, estimate the exposure or dose at a single point on the body and were not intended to be representative of the dose to individual organs. In this paper, we have used the values tabulated in ICRP Publication 74 [2] and ICRU Publication 43 [3] as the basis for developing a method that could be used to evaluate the differences between these monitored doses and organ doses.

To convert any of the above monitored doses to an accurate estimate of organ dose, the photon energy of the exposure must be considered. While knowledge of the facility specific energy spectrum would be ideal, in most cases, only photon doses within broad energy intervals are likely to be known. At DOE facilities in the United States for example, film badges in the mid-1960s used multiple absorbers to determine the dose from low energy x-rays, intermediate energy photons, and high energy photons. With these broad energy intervals, a mean or effective dose conversion factor is needed for organ dose determination.

The final step in determining the dose conversion factor requires an evaluation of the worker's exposure geometry which can vary significantly between facilities and job types within each facility. In general, most workers receive radiation exposure in an anterior-posterior orientation. Some workers, such as drum storage handlers, however, are exposed in more of an isotropic or rotational manner. In practice, most radiation exposures are received as a combination of anterior-posterior, rotational, and isotropic geometries.

The following section describes the technical approach used to develop a method for converting monitored dose to organ dose for each of the factors discussed above.

2. Methods

2.1. Monitoring Device Conversion

Many of the coefficients necessary to convert monitored dose to organ dose are contained in ICRP Publication 74 [2]. These are listed in that document by tissue of interest, exposure geometry, and radiation energy. These coefficients can be used to convert from ambient dose equivalent ($H^*(10)$) and personal dose equivalent ($H_p(10)$) to free-in-air KERMA (K_a) for various photon energies. Also included in ICRP 74 are the coefficients necessary to convert $H_p(10)$ to K_a. Since most early monitoring data was reported in units of exposure, and not a deep dose at 10 mm, the conversion from exposure in Roengten to ambient deep dose requires an additional step. This was accomplished using the factors provided in ICRU Publication 43 [3]. Once the monitored dose is converted to free-air KERMA, the organ dose is calculated as the product of free-air KERMA and the dose conversion factors (D_T/K_a). Equation 1 provides the general formula that can be used to convert $H_p(10)$ to organ dose for a given monitoring device.

$$DCF(D_{M,Hp(10)\rightarrow D_T}) = \frac{1}{\frac{H_p(10)}{K_a}} \times \frac{D_T}{K_a} \qquad \textit{Equation 1}$$

2.2. Energy Interval Estimation

As previously indicated, the energy of the exposure radiation must be known to estimate an organ dose. Past experience with monitoring data has indicated only broad energy interval information is available from personnel dosimeter devices such as film badges and thermoluminescent dosimeters. Furthermore, the radiation weighting factors that are applied in probability of causation calculations are subdivided into three photon energy intervals (< 30 keV, 30-200 keV, and >200 keV). ICRP Publication 74, however, provides dose conversion coefficients at discrete energies. To accommodate this difference, the dose conversion factors for each energy interval were fitted as a function of energy, *f(E),* and the area under the curve was integrated. Equation 2 provides an example of the how this was applied to the DCF calculation for intermediate photon energy (0.030 MeV – 0.20 MeV) irradiation of the red bone marrow. The area under the curve divided by the energy range results in a mean or effective dose conversion factor for the energy band of interest.

$$DCF(D_M, E_{\gamma,0.03-0.20MeV}) = \frac{\int_{0.03}^{0.20} f(E)dE}{Range} = 0.419 \frac{\text{BoneMarrow-Gy}}{\text{H}_\text{p}(10)\text{Gy}} \qquad \textit{Equation 2}$$

Figure 1 depicts the DCFs that were calculated using this method for the dose to red bone marrow for photon irradiation between 0.01 and 6.0 MeV. Since there are few operations at DOE facilities that result in photon exposures greater than 6 MeV, the upper bound for the calculation of the high-energy group photons was truncated at 6 MeV. For facilities such as large-scale accelerators, integration over the full range would be necessary.

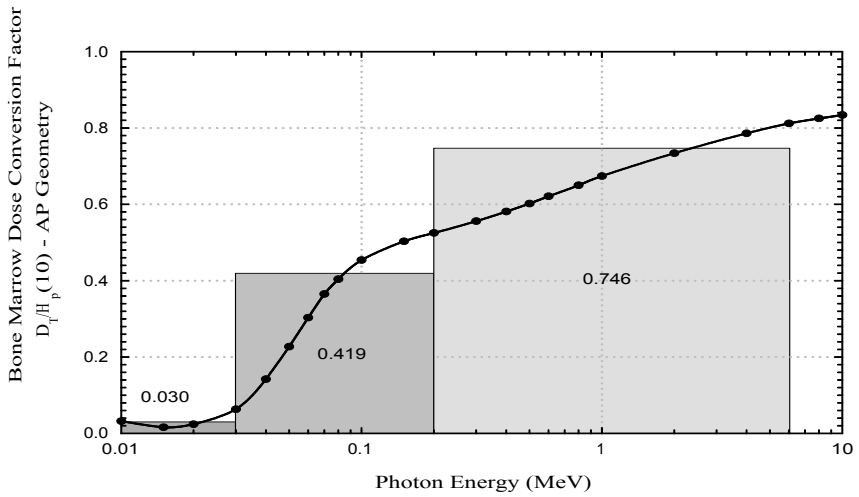

Figure 1. Red Bone Marrow Dose Conversion Factor (DCF) for the anterior-posterior geometry as a function of photon energy

2.3. Exposure geometry

There are six basic radiation exposure geometries in the work environment. With respect to the incident radiation these are: 1) anterior to posterior (AP); 2) posterior to anterior (PA); 3) left lateral (LLAT); 4) right lateral (RLAT); 5) rotational (ROT); and, 6) isotropic (ISO). Of these, only four (AP, PA, ROT, and ISO) are of primary interest in most occupational settings. While the AP exposure orientation is the most common geometry experienced by workers who handled radioactive materials, there are other jobs with different exposure orientations. For example, the isotropic exposure geometry might be representative of a worker assigned to a drum storage warehouse. A reactor worker refuelling a graphite reactor would likely receive their exposure in both the AP and ROT geometry. Some occupational medical exposures are in the PA exposure geometry.

Job specific exposure geometries, based on process evaluation and interviews, should be determined for each worker, however, the use of professional judgment may be required when detailed information is not available. In many circumstances workers may have multiple exposure geometries. To account for these different geometries, the organ doses can be weighted based on the amount of time spent in each exposure orientation, which results in a work specific Dose Conversion Factor *(DCF_W)* as shown in equation 3. As indicated, the geometry specific dose conversion factors are functions of the monitoring device and photon energy.

$$DCF\left(D_M, E_\gamma\right)_W = w_{AP} DCF\left(D_M, E_\gamma\right)_{AP} + w_{PA} DCF\left(D_M, E_\gamma\right)_{PA} + w_{ROT} DCF\left(D_M, E_\gamma\right)_{ROT} + w_{ISO} DCF\left(D_M, E_\gamma\right)_{ISO} \qquad \textit{Equation 3}$$

3. Discussion

The type of monitoring device, the exposure energy, and the exposure geometry can have a large impact on the estimated organ dose. With the exception of the thyroid, testes and bone surfaces at low energies, the modern monitored dose is always greater than the organ dose. Figure 2 provides organ dose conversion factors for bone marrow, breast and lung for exposure to 100 keV photons.

As indicated in Figure 2, the dose conversion factors from exposure measurements to organ dose are greater than the $H_p(10)$ to organ dose conversion factors. This is primarily the result of the inclusion of backscatter radiation in the calculation of personal dose equivalent. It should be noted that in the intermediate energy band, the DCF could vary by 40% depending on monitoring device alone.

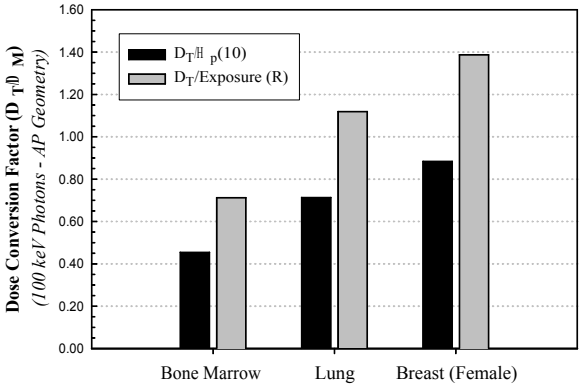

Figure 2. Comparison of organ dose conversion factors for selected organs at 100 keV irradiation

The sequence in how the dose conversion factor is computed can affect the value of the final dose conversion factor. The sequence of computation should be performed from the most specific or best-known data to the least specific data. In many cases, the monitoring device and calibration methodology is known. In addition, the energy intervals are mandated by the probability of causation methodology. Therefore these two components are calculated first and then the exposure geometry specific dose conversion factor is computed. However, if the exposure geometry were known more precisely than the energy spectrum, a work specific dose conversion factor as a function of energy should be developed before the energy interval integration. Finally, the integration under the curve to obtain effective dose conversion coefficients assumes a uniform distribution across the energy interval of interest. This assumption might not be applicable in all circumstances. When the photon energy spectrum can be well characterized, this information should be used.

While the methodology presented in this paper is described for photon exposures; the same methodology could be applied to external neutron and electron exposures. For neutron exposures, some consideration must be given to the ability of the monitoring device to detect different energy neutrons and the radiation weighting factors that might be applied.

4. Conclusions

It is possible using published information to convert monitored badge results into organ doses relatively easily. Using the methodology described in this paper, the magnitude of the differences between monitored external dose and organ dose can be evaluated. If desired, these differences could be accounted for in a worker's external dose reconstruction effort.

References

[1] The Energy Employees Occupational Illness Compensation Program Act, Public Law 106-398, 114 Stat. 1654, 1654A-1231 (October 2000), enacted as Title XXXVI of the Floyd D. Spence National Defense Authorization Act for Fiscal Year 2001.

[2] International Commission on Radiological Protection. *Conversion Coefficients for Use in Radiological Protection Against External Radiation*, ICRP Publication 74; Ann. ICRP 26(3/4); Pergamon Press, Oxford, England (1996).

[3] International Commission on Radiation Units and Measurements. *Determination of Dose Equivalents From External Radiation Sources - Part 2*, ICRU Report 43, International Commission on Radiation ICRU Units and Measurements, Bethesda Maryland. (1988).