CALCULATION METHODS FOR DETERMINING DOSE EQUIVALENT

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INTRODUCTION

A series of calculations of neutron fluence as a function of energy in an anthropomorphic phantom was performed to develop a system for determining effective dose equivalent for external radiation sources. Critical organ dose equivalents are calculated and effective dose equivalents are determined using ICRP-26 [1] methods. Quality factors based on both present definitions and ICRP-40 definitions are used in the analysis. The results of these calculations are presented and discussed.

The effective dose equivalent determined using ICRP-26 methods is significantly smaller than the dose equivalent determined by traditional methods. No existing personnel dosimeter or health physics instrument can determine effective dose equivalent. At the present time, the conversion of dosimeter response to dose equivalent is based on calculations for maximal or "cap" values using homogeneous spherical or cylindrical phantoms. The evaluated dose equivalent is, therefore, a poor approximation of the effective dose equivalent as defined by ICRP Publication 26.

DISCUSSION

Preliminary work was started in 1987 to develop methods to calculate and possibly experimentally determine effective dose equivalent. This work consisted of modifying the powerful computer code, Monte Carlo Neutron and Photon Transport (MCNP) [2], to run on a minicomputer. Next, a suitable anthropomorphic phantom was selected for the effective dose equivalent calculations. The male MIRD phantom was modeled as an input file for the MCNP code.

A number of calculations were performed with the MCNP code and the MIRD anthropomorphic phantom. The results were then used as input to a second code written at The Pacific Northwest Laboratory (PNL) to calculate dose equivalents to various tissues and calculate the effective dose equivalent as defined in ICRP Publication 26, with certain exceptions. The weighting factors used in the PNL calculations were specific to the male phantom and not an average of male and female as defined in ICRP Publication 26. The weighting factors used are given in Table 1. The weighting factors are slightly different than those given in ICRP-26 in that the female breasts were not included. Future calculation will be done with a female phantom and appropriate weighting factors.

TABLE 1. Effective Dose Equivalent for Monoenergetic Neutron Beams

Cell	Weighting Factor	Dose Equivalent for Each Tissue Per Unit Neutron Fluence Incident Upon Body, mrem per n/cm^2 100 keV Neutron Beam	1 MeV Neutron Beam
Lung	0.12	2.65×10^{-7}	8.85×10^{-6}
Liver	0.00	2.15×10^{-7}	8.22×10^{-6}
Stomach	0.06	2.69×10^{-7}	1.07×10^{-5}
Small Intestine	0.06	4.45×10^{-8}	4.62×10^{-6}
Upper Large Int.	0.06	7.10×10^{-8}	6.44×10^{-6}
Lower Large Int.	0.06	3.50×10^{-8}	3.94×10^{-6}
Testicles	0.25	1.97×10^{-6}	2.44×10^{-5}
Thyroid	0.03	9.33×10^{-7}	1.78×10^{-5}
Red Bone Marrow	0.15	2.89×10^{-9}	7.31×10^{-7}
Trunk	0.06	5.22×10^{-7}	8.43×10^{-6}
Effective dose equivalent per unit fluence incident upon body, mrem per n/cm^2		7.17×10^{-7}	1.16×10^{-5}

The methodology of ICRP Publication 26 requires that the dose equivalent be determined for various tissues in the body. The dose equivalent for each of these tissues is then multiplied by a weighting factor, and the products are summed to give the effective dose equivalent for the entire body. This method thus accounts for the attenuation of radiations within the body and the radiosensitivity of various tissues within the body. It also allows for the determination of effective dose equivalent in nonuniform fields and for the addition of dose equivalents from internal and external sources. In general, the effective dose equivalent is a more accurate estimator of the risks of radiation exposure than the currently defined dose equivalent.

Results from the MCNP calculations are shown in Table 1 for 100 keV and 1.0 MeV monoenergetic neutron beams. All organs listed are modeled mathematically in the computer code. The effective dose equivalent shown is for neutrons only and does not include the dose due to secondary photons. The MNCP code does, however, determine the effective dose equivalent due to secondary photons; that information is included in the curves shown in Figures 1 and 2, which show the conversion factors for the full energy range of the calculations.

Figure 1 demonstrates the differences between the conventional fluence-to-dose equivalent conversion factors and the effective dose equivalent conversion factors for the anterior irradiation with a parallel beam of monoenergetic neutrons. The effective dose equivalent is at least a factor of two lower than the conventional dose equivalent for most neutron energies. At the higher neutron energies above about 10 MeV, the effective dose equivalent values are closer to the conventional dose equivalent.

In ICRU Report 40 [3], a joint task group of the International Commission on Radiation Units and Measurements and the International Commission on Radiological Protection proposed a radical change in the definition of quality factor. The joint task group proposed that quality factor, which is now defined as a function of linear energy transfer (LET), be redefined as a function of the microdosimetric quality lineal energy. Lineal energy is a stochastic quantity that can be experimentally measured with instruments such as the tissue equivalent proportional counter. The quality factors in ICRU Report 40 are calculated at a point in tissue and were used to calculate the dose equivalent to the various tissues in the MIRD phantom, and the weighting factors of ICRU 26 were applied to determine the effective dose equivalent. The results of these calculations are presented in Figure 2 along with the conventional dose equivalent.

CONCLUSIONS

This calculational method is appropriate for most anticipated health physics monitoring situations. Variations in physical size of the human body can be taken into account as well as most of the potential exposure geometries (point source, beams, and isotropic). For many spectra, the effective dose equivalent is smaller in magnitude than dose equivalent determined by present methods. The effective dose equivalent is also more accurate in that it takes into account the radiosensitivity of the individual organs.

In the future, differences between the male and female phantoms and different sizes of phantoms will be studied. Experimental measurements will also be conducted with an anthropomorphic phantom to verify the calculations.

REFERENCES

[1] International Commission on Radiological Protection (ICRP). 1977. Recommendations of the International Commission on Radiological Protection. ICRP Publication 26, Pergamon Press, Oxford.

[2] Briesmeister, Judith F., ed. 1986. MCNP - A General Monte Carlo Code for Neutron and Photon Transport Version 3A. LA-7396M rev. 2, Los Alamos National Laboratory, New Mexico.

[3] International Commission on Radiation Units and Measurements (ICRU). 1986. The Quality Factors in Radiation Protection. ICRU Report 40, Bethesda, Maryland.

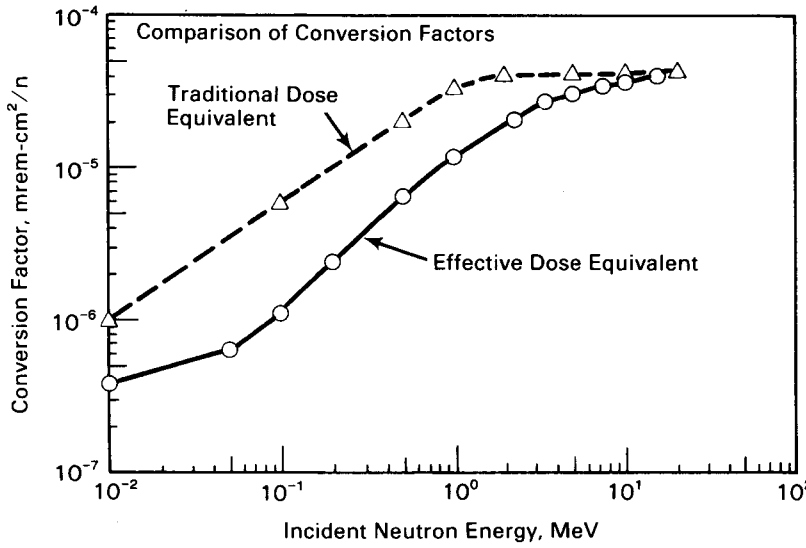

FIGURE 1. Comparison of Traditional and Effective Dose Equivalent

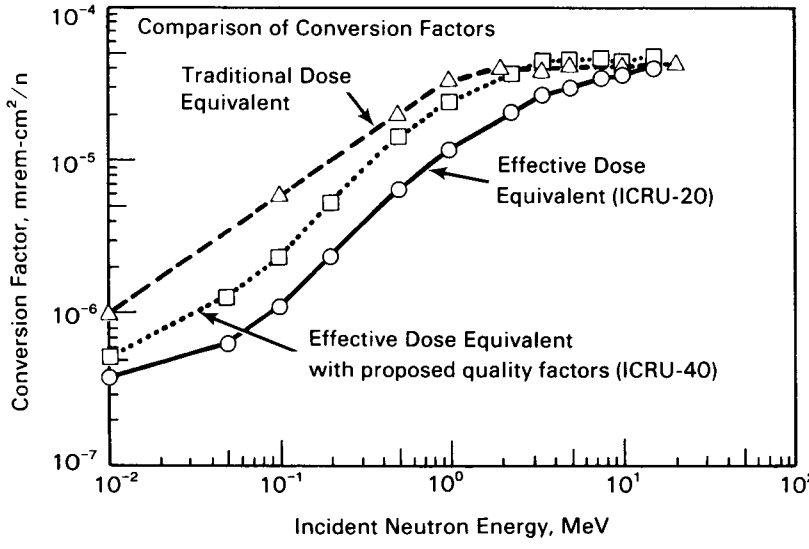

FIGURE 2. Comparison of Three Different Dose Equivalent Methods