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Photon Flux to Dose Rate Conversion Factors from Photon Exposure for Lung and Soft Tissues

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Abstract

The photon flux to dose conversion factor for the lung and the soft tissues from an idealized photon exposure at 1m AP was achieved using MCNPX®. The lung and the soft tissues of the modified Adult Male® phantom of ORNL were subjected to dose function modification, DE and DF. The estimated DF(E) for the energy range 0.1MeV to 15MeV compare favorably with the values of ANSI/ANS-6.1.1-1977.

Keywords: Photon Flux; Dose Rate; Conversion Factor; MCNPX; Tissue; Radiation Dose.

1. Introduction

The American Nuclear Society, ANS published the American National Standards Institute, ANSI standard on flux to dose factor, DF(E) in 1991 as a revision of the 1977 version. The 1991 version was however withdrawn in 2001[1,2], hence, making the 1977 version a relevant and reliable source for validating estimated DF(E) factors. There are however, reported values of a conversion factor before the ANS 1991 values [3]. Reference [1] made effort to update the equations similar to the ANSI/ANS -6.1.1-1991 by fitting the ICRP 116 dose coefficient to polynomial functions.

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Radiation protection quantities such as absorb dose, effective dose and dose equivalent play remarkable roles in radiation protection as they provide estimated insight into the biological effect of radiation exposures. However, these quantities cannot be measured directly when human tissues are exposed to radiation. For this reason, models of the human body, referred to as the phantoms have been in use for decades to achieve these measurements. In radiation dosimetry measurements, a vital and central role is played by the phantom that is used in simulating the body of human [4,5,6]. Phantoms have evolved lately due to the incident of computers but mathematical phantoms, such as the Adult Male® phantoms of ORNL have been very useful for these measurements for decades [4]. In this case, the tissues of the phantoms are represented by mathematical equations. In order to bridge the gap between the protection quantities and the operational quantities, conversion coefficients were introduced by scientific organizations. Such coefficients are available in, for instance ICRP Publication 21, ICRP Publication 74, ANSI/ANS 1977 and ANSI/ANS 1991 [5,6]. The flux to dose conversion factor, DF(E) is one of the relevant conversion coefficients in use. The DF(E) is for the MCNP DE and DF tally cards to convert estimated particle flux, cm^{-2} to dose equivalent rate [7,8]. Although, there are many datasets for conversion factor but often used sets are the ANSI/ANS-6.1.1-1977 [9,10] (derived from maximum dose equivalent, H), ANSI/ANS-6.1.1-1991 (derived from effective dose equivalent, H_E) and ICRP-74 (derived from effective dose, E) [1,11]. There is also ICRP-21 dataset but it differs from ANSI/ANS 1977 by >20% [7]. The energy range for ANSI/ANS 1977 is 0.01-15MeV while that of ANSI/ANS 1991 is 0.01-12MeV [12]. A discretional caveat is however emphasized in the use of conversion factors [7], this caveat provides the stimulus and the necessity for this study to ascertain how the result compares with the established values. The lung and the soft tissue data used for this study are the values derived for the Malaysian phantom (work in progress). The tissues considered as soft tissues in this study include the liver, stomach wall, testes, ovaries, brain, kidney, pancreas, spleen, gall bladder, heart and the small intestine. There are problems relating to the exact acceptable DF(E) standard value. The stochastic dose quality was explicitly defined but the conversion factor that will be used for its estimation was not stated, this provided for the acceptance of any 'reputable' set of values [10]. Despite the reported problems, dose conversion coefficient has been very resourceful in reconstruction and estimation of organ dose using ICRP 74 [13] and MCNP code has been a very relevant tool in calculating DF(E) [3]

1.1 The tally cards

The MCNP tally cards used are F4, F6, DE and DF. The F4 tally in MCNP measures the average flux in a cell or the track length estimate of particle flux, cm^{-2}.

$$F4 = \frac{1}{V}\int_{i} dE \int_{t_j} dt \int dV\, \varphi(\vec{r}, E, t) \text{ [5]} \tag{1}$$

F6 tally measures the energy deposition or track length estimate of heating, measured in MeV/g. The Heating number of F6 is given as:

$$H(E) = E - \sum_{i=1}^{3} p_i(E)\left[\bar{E}_{i,out}(E)\right] \text{ [5]} \tag{2}$$

The DE tally provides an added energy grid for the fluence to dose factor while the DF tally provide for an added fluence to dose conversion factor.

2. The Method

The F4 and F6 tallies of the modified Adult Male® phantoms of ORNL were further modified by dose function using the DE and the DF tally cards. A sample cut-out section of the tally card for 0.7MeV source is shown below.

384- f286:p 62 $ small intestine

385- de0:p $ Added energy grid for fluence to dose factor

386- df0:p $ Added fluence to dose conversion factor

387- nps 100000000

388- ctme 60

389- phys:p 0.7 0 0

The de0 and the df0 of line 385 and 386 are the DE and DF tallies, they indicated that all the tallies have the same dose conversion factors and the same log-log interpolation entries, recommended by [6]. It is also used to avoid repetition of tables.

2.1 The reduction of statistical uncertainties

The truncation technique was adopted in reducing the relative error in the simulation, using higher time and higher history cut-off. This technique is mostly used to reduce computer time [8] but it was used in this study to achieve reduction in the relative error. The number of photons history, nps was increased to 1E+8 and the cut off time set to 60minutes, whichever comes first. It's a waste of time tracking photons that thermalized in an irrelevant region [8], so irrelevant tissues were given zero importance. The trial runs were carried out and the MCNP statistical checks on the Tally Fluctuation Chart, TFC bins were monitored and noted. The statistics produced in MCNP include the relative error, R which is the ratio of the standard deviation of the mean to the mean and it point to the precision of the mean. The equation of the relative error in DF(E) is given by:

$$\mathrm{R_{DF(E)}} = \sqrt{(\overline{\mathrm{R_{F4}}})^2 + (\overline{\mathrm{R_{F6}}})^2} \ [14] \tag{3}$$

The figure of merit, FOM is the inverse of the product of the computer run time, T and the square of the relative error, R. $FOM = \frac{1}{T \times R^2}$ [8] (T = Computer Run Time, R = Relative Error) (4)

FOM is dependent on the computer used for the simulation since the configuration determine the computer run time. The details of the computer configuration used for the MCNPX simulation in this study is Intel(R) Core

(TM) i3-6100U CPU @ 2.30GHz 4GB RAM 64-bit OS ASUS Windows 10. The variance of variance, VOV is a measure of the accuracy of the mean and it is defined by

$$\mathrm{VOV} = \frac{S^2 S_{\bar{X}}^2}{S_{\bar{X}}^2} = \frac{\sum_{i=1}^{N}(x-\bar{x})^4}{\left[\sum_{i=1}^{N}(x-\bar{x})^2\right]^2} - \frac{1}{N}\ [8] \quad (5)$$

The relative error is < 0.05, the acceptable limit [7,12]. The VOV is <0.1, VOV→0 as nps→∞. FOM is constant and the Slope > 3 [15]. All these variables are equally important in ensuring accuracy and precision of the data but only the relative error is presented with the table of result.

2.2 The Limitation

The values estimated in this study is limited to the AP geometry and at 1m from the phantom.

3. Calculation of the DF(E)

The modified F4, F6 and the corresponding relative error data for each tissue from the MCNPX tally flux chart after simulation were noted and recorded. The mean and the standard deviation were estimated for the values of F4 and F6. The standard error in F4 and F6 is estimated using the equation:

$$\sigma = \text{Standard Error} = \frac{\text{Standard Deviation}}{\text{Number of Tissues,N}}\ [14] \quad (6)$$

The relative uncertainty in DF(E) is calculated from:

$$\frac{\sigma_{DF(E)}}{DF(E)} = \sqrt{\left(\frac{\sigma_{F4}}{F4}\right)^2 + \left(\frac{\sigma_{F6}}{F6}\right)^2}\ [14] \quad (7)$$

It should be noted that the standard error in F4 and F6 add in quadrature and the relative error for the modified F4 and F6 tallies of the lung and soft tissue were estimated from:

$$R_{DF(E)} = \sqrt{(\overline{R_{F4}})^2 + (\overline{R_{F6}})^2}\ [14] \quad (8)$$

The estimate of the DF(E) is obtained using the equation:

$$\overline{DF(E)} = \frac{\overline{F6}\ (\text{Mean, Dose Modified F6 Tally})}{\overline{F4}\ (\text{Mean, Dose Modified F4 Tally})} \quad (9)$$

4. Result and Discussion

The results for the modified tally cards were obtained using MCNPX® [16,17]. The values of the FOM is good, VOV is less than 0.1 and the Slope is within the acceptable limit. Table 1 present the estimated values of the DF(E) and the corresponding relative error, alongside the ANSI/ANS-6.1.1-1977[9] for validation because presenting measurements without the corresponding relative error is useless [15]. The relative error in DF(E) was calculated using equation 8 and from the values of the relative errors obtained from the MCNPX output result for each tissue. Definite uncertainty estimation improves the accuracy of measurements [18], hence, the relative uncertainty in DF(E) was calculated using equation 7 and reported. The DF(E) agrees within 20% range [7,19] of the ANS values for energies 0.1 to 0.2MeV. This means that the difference between the values obtained in this study and the ANS values is within the acceptable, established limit. For energies 0.3 to 0.8MeV, the DF(E) of this study interpolate and fit within the corresponding ANS range of values, this shows a good agreement. For energies 1.0 to 9.0MeV, the DF(E) agrees within the 20% range of the ANS values. For energies 11 to 15MeV, the DF(E) consistently agreed with the ANS corresponding values. Hence, this indicate consistency and agreement between the values obtained in this study and the ANS/ANSI 1977 values. The behavior of the DF(E) curve (Figure 1) show strong consistency with the ANSI/ANS 1977 curve at 1.0MeV > photon energy > 9MeV, it is however consistent within the ±20% agreement bracket [7,19] for 1.0MeV < photon energy < 9.0MeV. The observed difference within this region is still within the acceptable limit. Possible reasons for this variation may include the different phantom geometry used and/or depth of the photon penetration and/or the source direction [7,8]. The curve of the average photon heating number is given as figure 2 while the curve of the total photon cross section is given as figure 3. The MCNP library details of the radiation source used to generate the photon exposure is Ir-192, ρ=22.56g/cm^3, ZAID: 77193.30y, AWR: 192.96300, MCNP Library: LLLDOS, LLNL/ACTL. Date:<1983, Length: 243. The details of the MCNPX Visual Editor version used for the simulation is VISED – MCNPX version 2.7E Visual Editor Released April 2011: MCNPX Visual Plotter Version.

5. Conclusion

The construction of the radiation phantom from the derived internal tissue data for Malaysia population and the modified adult male phantom of the ORNL is in progress. it is inevitably necessary to ascertain how the conversion coefficient derived from the modified phantom compares with the established values. Hence, the essence of this study. This study intends to set the pace and provide the bedrock for further research into Malaysia based radiation phantom. The values of DF(E) obtained and presented in this study is specifically applicable to the lung and the soft tissue. It is the opinion of the authors that these values will be of valuable use in radiation protection and its application to human internal tissues.

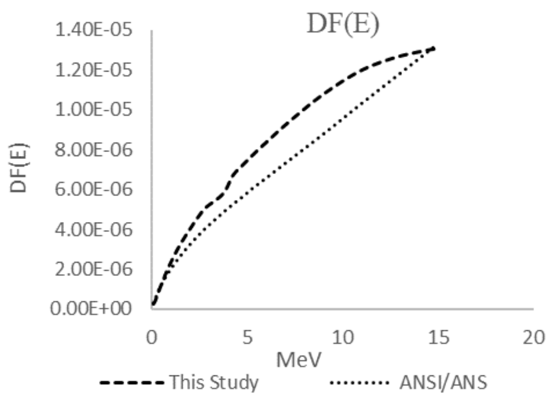

Figure 1: Graph of DF(E) (Lung and Soft Tissue) and ANSI/ANS-6.1.1-1977 against Energy

Table1: Photon Flux to Dose Rate Conversion

	DF(E) (rem/hr)/(p/cm^2-s)		
	This Study Modified Adult Male		
Energy MeV	**Mean ± Relative Uncertainty**	**Relative Error, R**	**ANSI/ ANS-6 .1.1-1977**
0.1	(2.42 ± 0.39)E-7	0.108	2.83E-07
0.2	(4.27 ± 0.62)E-7	0.060	5.01E-07
0.3	(6.93 ± 0.95)E-7	0.035	7.59E-07
0.4	(9.55 ± 1.23)E-7	0.024	9.85E-07
0.5	(1.20 ± 0.15)E-6	0.018	1.17E-06
0.6	(1.44 ± 0.18)E-6	0.015	1.36E-06
0.65	(1.52 ± 0.19)E-6	0.014	1.44E-06
0.7	(1.68 ± 0.20)E-6	0.014	1.52E-06
0.8	(1.90 ± 0.22)E-6	0.013	1.68E-06
1.0	(2.32 ± 0.26)E-6	0.011	1.98E-06
1.4	(3.07 ± 0.34)E-6	0.010	2.51E-06
1.8	(3.71 ± 0.40)E-6	0.010	2.99E-06
2.2	(4.29 ± 0.45)E-6	0.010	3.42E-06
2.6	(4.83 ± 0.50)E-6	0.010	3.82E-06
2.8	(5.07 ± 0.52)E-6	0.010	4.01E-06
3.75	(5.80 ± 0.74)E-6	0.010	4.83E-06
4.25	(6.70 ± 0.66)E-6	0.010	5.23E-06
4.75	(7.21 ± 0.71)E-6	0.010	5.60E-06
5.0	(7.45 ± 0.74)E-6	0.010	5.80E-06
5.25	(7.69 ± 0.76)E-6	0.010	6.01E-06
5.75	(8.15 ± 0.80)E-6	0.010	6.37E-06
6.25	(8.59 ± 0.84)E-6	0.010	6.74E-06
6.75	(9.03 ± 0.88)E-6	0.010	7.11E-06
7.5	(9.65 ± 0.94)E-6	0.010	7.66E-06
9.0	(1.08 ± 0.11)E-5	0.010	8.77E-06
11.0	(1.20 ± 0.12)E-5	0.015	1.03E-05
13.0	(1.27 ± 0.12)E-5	0.011	1.18E-05
15.0	(1.31 ± 0.13)E-5	0.012	1.33E-05

Factor, DF(E) data for lung and soft tissues Compared with the ANSI/ANS-6.1.1-1977 Data

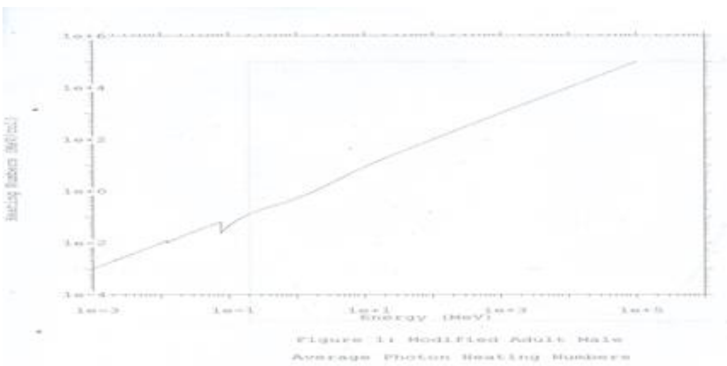

Figure 2: Average Photon Heating Numbers for the Modified Adult Male Phantom

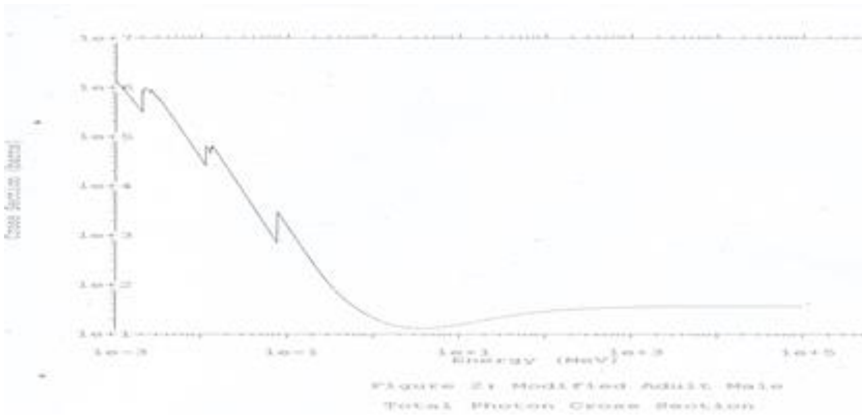

Figure 3: Total Photon Cross Section for the Modified Adult Male Phantom

6. Recommendation

The authors recommend further studies into the DF(E) estimates for the other geometries PA, ISO, LAT and ROT for this modified phantom.

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Reference

[1]. Mille M. M., Hertel N. E., Bergstrom P. M. and Lee C., 2018. Piecewise Polynomial Approximations to The ICRP 116 Effective Dose Coefficients: Photons and Neutrons. Radiation Protection Dosimetry (2018), Vol. 178, No. 3, pp. 310–321 doi:10.1093/rpd/ncx112. Downloaded on 25 July 2020 from https://academic.oup.com/rpd/article-abstract/178/3/310/4098852

[2]. ANS, 2004. ANS Issues Clarification on ANSI/ANS-6.1.1-1991, "Neutron and Gamma Ray Fluence-to-Dose Factors." (Nuclear News, October 2004) assessed on 8 August, 2020 from https://www.ans.org/file/374/6.1.1-1991-clarification-nn-1004.pdf

[3]. Rogers D. W. O., 1984. Fluence To Dose Equivalent Conversion Factors Calculated with EGS3 for Electrons from 100kev to 20 GeV and Photons from 11 KeV to 20 GeV. Health Physics Vol. 46, No.4 (April), pp. 891 914, 1984 Printed in the U.S.A.

[4]. Zankl, M., Becker, J., Lee, C., Bolch, W.E., Yeom, Y.S. and Kim, C.H., 2018. Computational Phantoms, ICRP/ICRU, and Further Developments. Annals of the ICRP. Volume 47, Issue 3-4, 1 October 2018, Pag 35-44

[5]. Behrens R., 2017. Compilation of Conversion Coefficients for the Dose to the Lens of the Eye. Radiation Protection Dosimetry. Vol. 174, No. 3, pp.348–370. https://doi:10.1093/rpd/ncw194 assessed on 17 July 2020 from: https://academic.oup.com/rpd/article-abstract/174/3/348/2527804

[6]. Huan L., Junli L., Rui Q., Zhen W., Yuxi P. and Chunyan L., 2017. Dose conversion coefficients for

Chinese reference adult male and female voxel phantoms from idealized neutron exposures. Journal of Nuclear Science and Tech. Vol. 54, No. 9, 921-932.https://doi.org/10.1080/00223131.2017.132368 Dataset:

[7]. X-5 Monte Carlo Team, 2003. MCNP A General Monte Carlo N-Particle Transport Code, Version 5 Volume I: Overview and Theory. LA-UR-03-1987

[8]. Shultis J. K. and Faw R. E., 2011. Introduction to the MCNP Code. LANL

[9]. American National Standards Institute, 1977. Neutron and gamma-ray flux-to-dose-rate factors. ANSI/ANS-6.1.1-1977. La Grange Park, IL: American Nuclear Society (1977).

[10]. Shores E. F. and Brown T. H., 2002. Fluence-to-Dose Confusion Regarding External Dose Determination within the DOE Complex. American Nuclear Society 2002 Winter Meeting November 17-21, 2002 Washington, D.C., USA. LA-UR-02-4042

[11]. Shore E. F. and Brown T. H., 2002. Fluence-to-Dose Confusion Regarding External Dose Determination within the DOE Complex. American Nuclear Society Winter Meeting November 17-21, 2002, Washington, D.C., USA

[12]. Robinson A., El-Guebaly L. & Henderson D., 2010. Evaluation of Biological Dose for ARIES-CS and Comparison with Approximate Contact Dose Approach. Fusion Technology Institute, Madison.http://fti.neep.wisc.edu

[13]. Timothy D. T., Keith A. M., Richard T., Matthew H. S. and James W. N., 2017. Implementation of ICRP 116 Dose Conversion Coefficients for Reconstructing Organ Dose in a Radiation Compensation Program.Radiation Protection Dosimetry. 2017 Apr 1; 173(1-3): 131–137. doi: 10.1093/rpd/ncw305

[14]. University of North Carolina, 2011. College Physics Labs Mechanics: Measurements and Error Analysis assessed on July 25, 2020 fromhttps://www.webassign.net/question_assets/unccolphysmechl1/measurements/manual.html

[15]. Hussein E., 2020. Chapter 11: Uncertainty Analysis in MCNP in: Monte Carlo Particle Transport in MCNP. Assessed July 19, 2020 from https://canteach.candu.org/Content%20Library/20043524.pdf

[16]. ICRP, 2010. Conversion Coefficients for Radiological Protection Quantities for External Radiation Exposures. ICRP Publication 116, Ann. ICRP 40(2-5)

[17]. Uhlář, R and Alexa, P., 2019. MCNP Approaches for Dose Rates Modelling in Laboratory for Neutron Activation Analysis and Gamma Spectrometry at Ostrava. Radiation Protection Dosimetry Volume 185, Issue 1, 1 November 2019, Pages 1-8

[19]. Chadia R., Panagiotis A., Burçin O. H., John K. S., Samaneh B., Elham Al F., Buddha R. S., Baldandorj M., Leeda M., Muditha R. and Mohamed A., 2020. Uncertainty Evaluation in Measurement of the Personal dose Equivalent at Nine Individual Monitoring Services in Asia and the Pacific Region, *Radiation Protection Dosimetry*, ncaa093, https://doi.org/10.1093/rpd/ncaa093

[20]. ICRP, 2010. Conversion Coefficients for Radiological Protection Quantities for External Radiation Exposures. ICRP Publication 116, Ann. ICRP 40(2-5)