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The Lung and Soft Tissue Stopping Power Estimates for a Modified Phantom Using MCNPX

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Abstract:- The Adult Male® and Adult Female® phantoms of ORNL were modified with Ir-192 source and additional tally cards from the MCNP® data library. The lung and eleven soft tissues were used for the study. The soft tissues include Liver, Stomach, Ovaries, Testes, Brain, Thyroid, Kidney, Pancreas, Gall Bladder, Heart, and the Small Intestine. The computational simulation was achieved using MCNPX with nps of 10^7, and the data set of the lung and soft tissues derived for Malaysian population [14]. The relative error, R was <0.05 for F4 and the F6 tallies across the energy range studied. The results obtained for 0.1-10.0 MeV energies for the F4 and F6 tallies were used to estimate the mass stopping power, S/ρ (MeVg^{-1}cm^2) and the linear stopping power, S (MeV/cm). The result compares favorably among the tissues. This result is very relevant and useful in validating an on-going lung and soft tissue model construction.

Keywords:- *Stopping Power, Radiation Phantom, MCNPX, Tissues, Photon Depth, Photon Area Density*

I. INTRODUCTION

When a medium is exposed to ionizing radiation and photon energy passes through it, the inelastic collisions that occur greatly characterize the particle transport [1]. The energy loss during the transport process [2] account for the continuous slowing down approximation, CSDA called stopping power [1,2]. The stopping power is rarely measured [3] but it has been measured for protons [4-8], electron interactions with humans [9] and from first principle to enhance research validation and empiricism reduction [10]

A. Linear Stopping Power, S

The linear stopping power, S is the energy loss per unit length, $\frac{dE}{dx}$ [3] or average energy lost by charged particles per unit path length, $-\frac{dE}{dx}$ [1]. Unit: MeV/cm.

B. Mass Stopping Power, S/ρ

$$\frac{1}{\rho}S_{el} = -\left(\frac{dE}{\rho ds}\right)_{el} = N_a Z \int_{W_{min}}^{W_{max}} W \frac{d\sigma}{dW} dW \quad [2] \qquad (1)$$

and S/ρ is $\frac{1}{\rho}\frac{dE}{dx}$ [2]. Unit: MeVg^{-1}cm^2.

Rearranging the unit, $\frac{S}{\rho} = \frac{MeV}{(g/cm^2)}$ (2)

II. METHOD AND MATERIAL

Ir-192[11] and additional tallies were used for the modification, MCNPX F4 measure the fluence, cm^{-2} and F6 measure MeV/g [12,13]. The tissue mass and density are presented in Table 1, the table is the derived data set for Malaysia population [14].

Dimensionally, $\frac{\text{Tally 6}}{\text{Tally 4}} = \frac{S}{\rho}$ (MeVg^{-1}cm^2) (3)

The source is 1m AP from the trunk of the phantom. The AP geometry specify that the photons are incident on the front of the phantom [15].

Tissue	Male, g	Female, g	Density, ρ
Lung	1110.26	711.00	0.25
Liver	1729.31	539.35	1.04
Stomach Wall	147.70	110.68	
Testes	37.00	-	
Ovaries	-	10.32	
Brain	1470.25	1179.10	
Thyroid	19.85	16.88	
Kidney	322.98	254.20	
Pancreas	119.10	79.73	
Spleen	161.49	144.45	
Gall Bladder	9.08	7.50	
Heart	147.70	110.68	
Small Intestine	625.78	457.74	

Table 1:- Table of lung and soft tissues mass and density [14]

A. The Calculation

The values of the F4 and the F6 output results are obtained directly from the MCNPX result after simulation. The relative error, R for the F4 and F6 data retrieved from the tally fluctuation chart is < 0.05 for the photon energies studied. The ratio of F6 to F4 yield the mass stopping power while the product of the mass stopping power and the density yield the linear stopping power. The Figure 1 show the flow of the calculation.

B. The Design Flow Chart

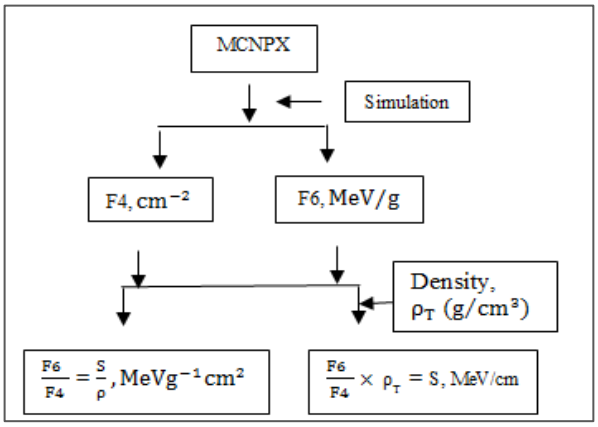

Fig 1:- Schematic Design of the Study Estimates

III. THE RESULT AND DISCUSSION

The linear stopping power and the mass stopping power recorded for the modified female phantom is greater than that of the male phantom by about 0.038% on the average at lower energies ≤0.1 MeV while it is on average of 0.1% less at higher energies ≥0.2 MeV. The linear stopping power is an estimate of the energy and the depth the photon travels in the tissue while the mass stopping power is a pointer to the energy and the area covered by the photon when traversing a tissue. Despite lower mass of the female tissues, compare to the male; it is evident that the photons travel deeper and cover wider area at lower energies ≤0.1 MeV in the female than in the male. However, the pattern is reversed at higher energies. This observed pattern is consistent for all the tissues studied. The Table 2 to Table 5 present the values of S and S/ρ for the male and the female.

The curves of the mass stopping power is presented in figure 2. The S/ρ vs MeV curve flattens after a certain energy point. This flattening behavior is also reported in [16] as it is considered a very important characteristic. The point is defined in [3] as $E_k \approx 3m_e c^2$.

IV. CONCLUSION

The estimation of the linear stopping power and the mass stopping power is a very important tool in validating the result from experiment. This result, obtained from MCNPX idealized photon exposure is very crucial and relevant as it will serve as a basis for justifying the result from experiment.

V. RECOMMENDATION

The authors recommend further efforts in estimating the linear and the mass stopping powers at energies >10MeV but within the medical diagnostic energy range.

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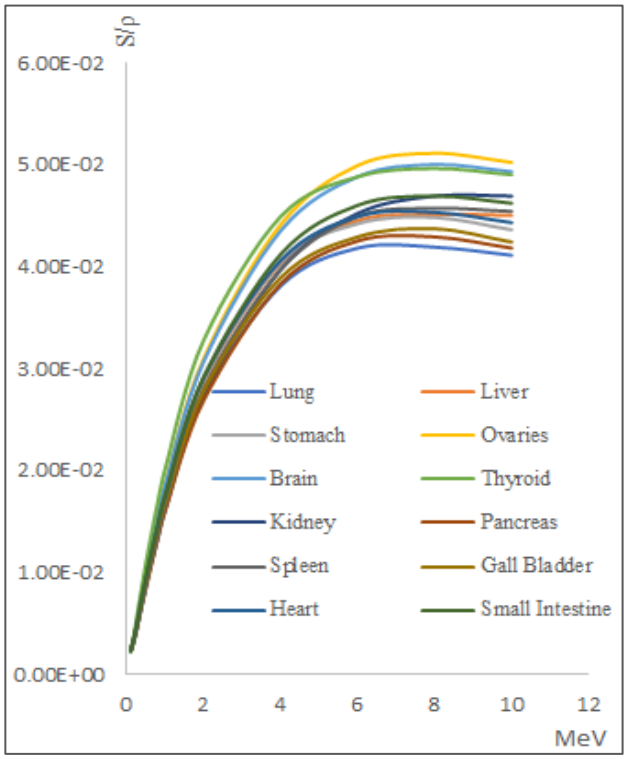

Fig 2:- S/ρ vs Energy

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Energy, MeV	0.1	0.2	0.3	0.4	0.5	0.6	0.8	1	2	4	6	8	10
Lung	6.11E-04	9.43E-04	1.41E-03	1.86E-03	2.31E-03	2.71E-03	3.47E-03	4.19E-03	6.84E-03	9.52E-03	1.05E-02	1.05E-02	1.03E-02
Liver	2.42E-03	3.88E-03	5.93E-03	7.92E-03	9.81E-03	1.16E-02	1.50E-02	1.81E-02	3.00E-02	4.19E-02	4.63E-02	4.69E-02	4.68E-02
Stomach	2.40E-03	3.88E-03	5.42E-03	7.97E-03	9.86E-03	1.17E-02	1.51E-02	1.83E-02	3.00E-02	4.20E-02	4.60E-02	4.65E-02	4.53E-02
Ovaries	2.37E+03	3.94E-03	6.13E-03	8.29E-03	1.04E-02	1.25E-02	1.61E-02	1.94E-02	3.22E-02	4.59E-02	5.19E-02	5.31E-02	5.22E-02
Brain	2.35E-03	4.05E-03	6.24E-03	8.43E-08	1.05E-02	1.24E-02	1.60E-02	1.93E-02	3.20E-02	4.52E-02	5.07E-02	5.20E-02	5.13E-02
Thyroid	2.31E-03	4.29E-03	6.82E-03	9.10E-03	1.14E-02	1.34E-02	1.75E-02	2.10E-02	3.41E-02	4.67E-02	5.07E-02	5.16E-02	5.10E-02
Kidney	2.50E-03	3.67E-03	5.47E-03	7.23E-03	8.96E-03	1.07E-02	1.38E-02	1.69E-02	2.85E-02	4.13E-02	4.70E-02	4.88E-02	4.88E-02
Pancreas	2.43E-03	3.70E-03	5.45E-03	7.25E-03	8.95E-03	1.07E-02	1.38E-02	1.68E-02	2.80E-02	3.99E-02	4.42E-02	4.47E-02	4.34E-02
Spleen	2.44E-03	3.71E-03	5.58E-03	7.46E-03	9.30E-03	1.10E-02	1.43E-02	1.72E-02	2.91E-02	4.12E-02	4.67E-02	4.75E-02	4.72E-02
Gall Bladder	2.50E-03	3.90E-03	5.66E-03	7.69E-03	9.53E-03	1.12E-02	1.47E-02	1.76E-02	2.89E-02	4.05E-02	4.46E-02	4.54E-02	4.41E-02
Heart	2.40E-03	3.87E-03	5.91E-03	7.92E-03	9.84E-03	1.17E-02	1.50E-02	1.82E-02	3.03E-02	4.22E-02	4.67E-02	4.71E-02	4.61E-02
Small Intestine	2.40E-03	3.94E-03	6.01E-03	8.08E-03	1.00E-02	1.18E-02	1.52E-02	1.84E-02	3.04E-02	4.29E-02	4.78E-02	4.88E-02	4.81E-02

Table 2:- Linear Stopping Power, S (MeV/cm) of the Modified Adult Female

Energy, MeV	0.1	0.2	0.3	0.4	0.5	0.6	0.8	1	2	4	6	8	10
Lung	2.44E-03	3.77E-03	5.66E-03	7.45E-03	9.22E-03	1.09E-02	1.39E-02	1.67E-02	2.74E-02	3.81E-02	4.18E-02	4.19E-02	4.11E-02
Liver	2.33E-03	3.74E-03	5.70E-03	7.62E-03	9.43E-03	1.11E-02	1.44E-02	1.74E-02	2.88E-02	4.03E-02	4.45E-02	4.51E-02	4.50E-02
Stomach	2.31E-03	3.73E-03	5.22E-03	7.66E-03	9.48E-03	1.12E-02	1.45E-02	1.76E-02	2.89E-02	4.04E-02	4.42E-02	4.48E-02	4.36E-02
Ovaries	2.28E-03	3.79E-03	5.90E-03	7.97E-03	1.00E-02	1.20E-02	1.54E-02	1.87E-02	3.10E-02	4.41E-02	4.99E-02	5.11E-02	5.02E-02
Brain	2.26E-03	3.90E-03	6.00E-03	8.10E-03	1.01E-02	1.19E-02	1.54E-02	1.86E-02	3.07E-02	4.35E-02	4.88E-02	5.00E-02	4.93E-02
Thyroid	2.22E-03	4.12E-03	6.56E-03	8.75E-03	1.10E-02	1.30E-02	1.68E-02	2.02E-02	3.28E-02	4.49E-02	4.88E-02	4.96E-02	4.90E-02
Kidney	2.40E-03	3.53E-03	5.26E-03	6.95E-03	8.62E-03	1.03E-02	1.33E-02	1.62E-02	2.74E-02	3.97E-02	4.52E-02	4.69E-02	4.69E-02
Pancreas	2.33E-03	3.56E-03	5.24E-03	6.97E-03	8.61E-03	1.02E-02	1.33E-02	1.61E-02	2.69E-02	3.83E-02	4.25E-02	4.29E-02	4.18E-02
Spleen	2.34E-03	3.56E-03	5.36E-03	7.17E-03	8.95E-03	1.06E-02	1.37E-02	1.66E-02	2.80E-02	3.97E-02	4.49E-02	4.57E-02	4.54E-02
Gall Bladder	2.40E-03	3.75E-03	5.44E-03	7.39E-03	9.16E-03	1.08E-02	1.41E-02	1.69E-02	2.78E-02	3.89E-02	4.29E-02	4.37E-02	4.24E-02
Heart	2.31E-03	3.73E-03	5.69E-03	7.61E-03	9.46E-03	1.12E-02	1.45E-02	1.75E-02	2.91E-02	4.06E-02	4.49E-02	4.53E-02	4.43E-02
Small Intestine	2.31E-03	3.78E-03	5.78E-03	7.77E-03	9.62E-03	1.14E-02	1.46E-02	1.77E-02	2.92E-02	4.12E-02	4.60E-02	4.69E-02	4.62E-02

Table 3:- Mass Stopping Power, S/ρ (MeV g-1 cm2) of the Modified Adult Female

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Energy, MeV	0.1	0.2	0.3	0.4	0.5	0.6	0.8	1	2	4	6	8	10
Lung	5.89E-04	9.77E-04	1.48E-03	1.95E-03	2.48E-03	2.93E-03	3.76E-03	4.55E-03	7.52E-03	1.04E-02	1.16E-02	1.17E-02	1.15E-02
Liver	2.49E-03	3.76E-03	5.65E-03	7.51E-03	9.35E-03	1.11E-02	1.44E-02	1.73E-02	1.43E-02	4.05E-02	4.51E-02	4.49E-02	4.50E-02
Stomach	2.30E-03	3.77E-03	5.83E-03	7.67E-03	9.37E-03	1.12E-02	1.47E-02	1.75E-02	2.86E-02	4.11E-02	4.42E-02	4.41E-02	4.33E-02
Ovaries	2.32E-03	4.22E-03	6.99E-03	9.69E-03	1.24E-02	1.42E-02	1.85E-02	2.27E-02	3.69E-02	4.88E-02	5.46E-02	5.78E-02	5.65E-02
Brain	2.33E-03	4.05E-03	6.24E-03	8.36E-03	1.03E-02	1.23E-02	1.60E-02	1.90E-02	3.11E-02	4.42E-02	5.00E-02	5.11E-02	5.04E-02
Thyroid	2.65E-03	4.41E-03	6.73E-03	9.27E-03	1.20E-03	1.24E-02	1.66E-02	2.11E-02	3.50E-02	4.80E-02	5.24E-02	5.09E-02	5.57E-02
Kidney	2.63E-03	3.50E-03	5.25E-03	6.89E-03	8.53E-03	1.03E-02	1.29E-02	1.60E-02	2.69E-02	3.87E-02	4.48E-02	4.68E-02	4.59E-02
Pancreas	2.69E-03	3.67E-03	5.36E-03	6.71E-03	8.42E-03	9.89E-03	1.31E-02	1.60E-02	2.61E-02	3.74E-02	4.19E-02	4.22E-02	4.21E-02
Spleen	2.41E-03	3.84E-03	5.23E-03	7.28E-03	8.56E-03	1.07E-02	1.35E-02	1.60E-02	2.80E-02	3.92E-02	4.40E-02	4.52E-02	4.38E-02
Gall Bladder	3.14E-03	3.33E-03	5.04E-03	6.57E-03	8.61E-03	1.03E-02	1.40E-02	1.65E-02	2.70E-02	3.96E-02	4.35E-02	4.19E-02	4.19E-02
Heart	2.38E-03	3.84E-03	5.45E-03	7.45E-03	9.39E-03	1.11E-02	1.45E-02	1.73E-02	3.86E-02	4.04E-02	4.44E-02	4.43E-02	4.43E-02
Small Intestine	2.43E-03	3.73E-03	5.89E-03	7.59E-03	9.59E-03	1.12E-02	1.45E-02	1.75E-02	2.91E-02	4.06E-02	4.51E-02	4.64E-02	4.56E-02

Table 4:- Linear Stopping Power, S (MeV/cm) of the Modified Adult Male

Energy, MeV	0.1	0.2	0.3	0.4	0.5	0.6	0.8	1	2	4	6	8	10
Lung	2.36E-03	3.91E-03	5.94E-03	7.79E-03	9.93E-03	1.17E-02	1.50E-02	1.82E-02	3.01E-02	4.16E-02	4.62E-02	4.69E-02	4.60E-02
Liver	2.39E-03	3.61E-03	5.44E-03	7.22E-03	8.99E-03	1.07E-02	1.38E-02	1.67E-02	1.37E-02	3.90E-02	4.33E-02	4.32E-02	4.33E-02
Stomach	2.21E-03	3.62E-03	5.60E-03	7.38E-03	9.01E-03	1.07E-02	1.41E-02	1.68E-02	2.75E-02	3.95E-02	4.25E-02	4.24E-02	4.16E-02
Ovaries	2.23E-03	4.06E-03	6.72E-03	9.32E-03	1.19E-02	1.37E-02	1.78E-02	2.19E-02	3.55E-02	4.69E-02	5.25E-02	5.56E-02	5.43E-02
Brain	2.24E-03	3.89E-03	6.00E-03	8.04E-03	9.91E-03	1.18E-02	1.51E-02	1.83E-02	2.99E-02	4.25E-02	4.81E-02	4.91E-02	4.84E-02
Thyroid	2.55E-03	4.24E-03	6.47E-03	8.92E-03	1.08E-02	1.20E-02	1.60E-02	2.03E-02	3.36E-02	4.61E-02	5.04E-02	4.89E-02	5.36E-02
Kidney	2.53E-03	3.37E-03	5.05E-03	6.62E-03	8.20E-03	9.86E-03	1.24E-02	1.54E-02	2.58E-02	3.72E-02	4.31E-02	4.50E-02	4.42E-02
Pancreas	2.59E-03	3.53E-03	5.15E-03	6.45E-03	8.09E-03	9.51E-03	1.26E-02	1.54E-02	2.51E-02	3.60E-02	4.03E-02	4.06E-02	4.05E-02
Spleen	2.32E-03	3.69E-03	5.03E-03	7.00E-03	8.23E-03	1.03E-02	1.29E-02	1.54E-02	2.69E-02	3.77E-02	4.23E-02	4.35E-02	4.21E-02
Gall Bladder	3.02E-03	3.20E-03	4.84E-03	6.31E-03	8.28E-03	9.90E-03	1.35E-02	1.58E-02	2.60E-02	3.81E-02	4.18E-02	4.03E-02	4.03E-02
Heart	2.29E-03	3.69E-03	5.24E-03	7.16E-03	9.03E-03	1.07E-02	1.40E-02	1.67E-02	3.71E-02	3.89E-02	4.27E-02	4.26E-02	4.26E-02
Small Intestine	2.34E-03	3.63E-03	5.66E-03	7.30E-03	9.22E-03	1.08E-02	1.39E-02	1.68E-02	2.80E-02	3.90E-02	4.33E-02	4.46E-02	4.38E-02

Table 5:- Mass Stopping Power, S/ρ (MeV g^{-1} cm^2) of the Modified Adult Male