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CSDA Range and Stopping Power Calculation Using Bethe-Bloch Formula for Proton in Common Human Cancer Tissues

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Proton therapy is used for the cure of tumors effectively, but its efficiency depends on the accuracy of the stopping power and range values. In this research, we calculated the stopping power and range values of biological human soft and hard tissues (blood, brain, skeleton-cortical bone, and skin) of both child and adult at the energies ranging from 1MeV to 350 MeV. We collected data from ICRU Report 46 and calculated the stopping power using the Bethe-Bloch formula. And, the value of range was calculated by applying the continuous slowing down approximation (CSDA) method. The stopping power and range values of tissue results have been compared with the program called SRIM. Moreover, the results of the stopping power versus energy and the range versus energy have been presented graphically. A proper agreement is found between the gained and the SRIM results and varies almost linearly with energy up to 250 MeV.

1. Introduction

In recent years, the theoretical and experimental study of SP and range of charged particles are increasing immensely in radiation physics. Many theoretical, as well as experimental studies have been established on this topic quite efficiently. The calculation of stopping power and range of proton plays an important role in proton and cancer therapy. Hence, precise knowledge of SP and range of protons is needed for the exact dosimetry of proton radiation. When studying the SP and range of proton in a biological target, one must determine or collect data experimentally or ICRU report. Scientists are working on the SP and range of protons in human tissues (skin, bone, blood, kidney, liver, brain, breast, etc.) in order to improve proton therapy in medical physics.

In this study, we have collected the composition of human body tissue's data from ICRU report 44 and 46. The composition of the human body gradually changes as the child becomes adult until the associate organs mature completely. The values of SP and range vary mostly by the difference of target materials. Proton and cancer therapy have been developing on the basis of this difference. So, we collected data from the selected body tissues (blood, brain, skeleton-cortical bone and skin) of both child and adult in this study and calculated the values of SP and range of proton.

Table 1: The elemental compositions and mass densities of some human body tissues.

Tissues	Elemental composition (percentage by mass)					ρ(g/cm^3)
	H	C	N	O	Others	
Blood (child)	10.0	13.1	4.0	72.0	0.1 Na, 0.1 P, 0.2 S, 0.2 Cl, 0.2 K, 0.1 Fe	1.07
Blood (adult)	10.2	11.0	3.3	74.5	0.1 Na, 0.1 P, 0.2 S, 0.3 Cl, 0.2 K, 0.1 Fe	1.06
Brain (child)	10.7	9.1	1.6	77.6	0.2 Na, 0.3 P, 0.1 S, 0.2 Cl, 0.2 K	1.03
Brain (adult)	10.7	14.5	2.2	71.2	0.2 Na, 0.4 P, 0.2 S, 0.3 Cl, 0.3 K	1.04
Skeleton-cortical bone (child)	3.8	16.0	4.4	44.3	0.1 Na, 0.2 Mg, 9.9 P, 0.3 S, 21.0 Ca	1.83
Skeleton-cortical bone (adult)	3.4	15.5	4.2	43.5	0.1 Na, 0.2 Mg, 10.3 P, 0.3 S, 22.5 Ca	1.92

Skin (child)	10.4	10.4	2.8	75.5	0.2 Na, 0.1 P, 0.2 S, 0.3 Cl, 0.1 K	1.05
Skin (adult)	10.0	20.4	4.2	64.5	0.2 Na, 0.1 P, 0.2 S, 0.3 Cl, 0.1 K	1.09

The SP of a charged particle, S is defined as a differential energy loss of that charged particle within material divided by the corresponding differential path length:

$$S(E) = -\frac{dE}{dx} \quad (1)$$

Here, SP is in negative sign because the energy of charged particles gradually decreases as long as they are interacting with the material. When the particle velocity decreases, S is started to increase.

And the total SP is the sum of nuclear and electronic SP.

$$S_{tot}=S_{el}(E)+S_{nuc}(E) \quad (2)$$

Nuclear SP arises from elastic Coulomb collisions with the target's nucleons which is so small that it is only significant at low energies. And this research paper is based on high energies up to 350 MeV. Here SP means entire electronic SP which is based on inelastic collisions with target's electrons and neglected nuclear SP.

Range, R of a charged particle is defined as the distance of that charged particle travel from its source to the target material. Continuous slowing down approximation (CSDA) is a commonly used method to calculate the range of the particle in the target matter.

2. Material and methods

2.1 Calculations of stopping power

Bethe-Bloch is a common formula to determine SP of any charged particle. At low energies, for small velocities of charged particle $\beta<<1$, this formula gives negative results for energies less than the mean excitation energy (I). And this formula is used to calculate SP at high energies because on those energies the charged particle does not carry any electrons with it.

-dE/dx is also known as specific energy and this energy loss can be described using classical expression. This expression is known as Bethe-Bloch formula. According to Bethe-Bloch formula, the stopping power of charged particle will increase as the charged particle starts to collide with matter and decreases its energy. This formula can also be described using relativistic quantum mechanics. This formula is for heavy charged particle like proton and is written as:

$$-\frac{dE}{dx}=\frac{4\pi nz^2k_0{}^2e^4}{mv^2}[\ln\frac{2mv^2}{I}-\ln(1-\beta^2)-\beta^2] \quad (3)$$

Where, e = electronic charge, m = electron rest mass, n = number of electrons per unit volume in the absorber, $k = 1/4\pi\varepsilon_0$, v = velocity of the particle, z = multiple of electron charge, I = mean excitation potential of the absorber, $\beta = v/c$ (v is the speed of the particle and c is the speed of light in a vacuum).

Mean excitation potential of the absorber $I = \hbar\omega$ is one of the challenging parameters to evaluate in the Bethe-Bloch expression. Mean excitation potential of the absorber I, is the only nontrivial material property in this formula. The SP of proton is mostly depends on the accuracy of the mean excitation potential of the absorber. Mean excitation potential of the absorber can be determined by experiment or there are various simple rules have been using to estimate this.

$$I = 12 + 7, Z < 13 \quad (4)$$

$$I = 9.76Z + \frac{58.5}{Z^{0.19}}, Z \geq 13 \quad (5)$$

The speed of a charged particle is commensurable to the speed of light that requires relative correction and so Bethe-Bloch formula is also called relative correction formula. β is the proton's velocity and can be determined by experiment or using,

$$E = \frac{1}{2}mv^2$$

$$\text{Or, } v = \sqrt{\frac{2E}{m}} \quad (6)$$

Here, the number of electrons per unit volume in the absorber can be calculated by

$$n = \frac{N_A.Z.\rho}{A.M_u} \quad (7)$$

Where, Z= atomic number of the target material, ρ= density of the target material, N_A= Avogadro number, A= atomic mass of the target material, M_u= molar mass constant.

Table 2: Showing the proton energy in MeV and the stopping power for values for Blood and Brain. Here, %T represents the percentage difference of this work values from SRIM stopping power

Energy (MeV)	Stopping power in MeV/g/cm^2 for Blood (child)			Stopping power in MeV/g/cm^2 for Blood (adult)			Stopping power in MeV/g/cm^2 for Brain (child)			Stopping power in MeV/g/cm^2 for Brain (adult)		
	SRIM	This work	%T	SRIM	This work	%T	SRIM	This work	%T	SRIM	This work	%T
1	250.50	283.15	13.03	250.20	282.18	12.78	250.31	282.71	12.94	250.81	284.55	13.45
2	163.21	189.67	16.21	162.81	188.43	15.74	163.91	190.14	16.00	163.62	190.03	16.14
3	119.97	138.23	15.22	119.68	137.66	15.02	120.48	139.41	15.71	120.28	139.17	15.71
4	95.92	107.75	12.33	95.68	106.68	11.50	96.27	108.38	12.58	96.12	108.21	12.58
5	80.45	86.29	7.26	80.27	85.51	6.53	80.76	86.45	7.05	80.63	86.35	7.09
6	69.62	74.81	7.45	69.46	74.02	6.56	69.87	75.06	7.43	69.76	74.94	7.43
7	61.56	66.39	7.85	61.42	66.14	7.68	61.78	66.79	8.11	61.69	66.53	7.85
8	55.30	59.61	7.79	55.17	59.44	7.74	55.50	60.07	8.23	55.41	59.88	8.07
9	50.29	53.22	5.83	50.18	52.91	5.44	50.48	53.32	5.63	50.39	53.19	5.56
10	46.19	48.42	4.83	46.09	48.12	4.40	46.36	48.53	4.68	46.29	48.47	4.71
20	26.26	28.38	8.07	26.21	28.28	7.90	26.36	28.51	8.16	26.32	28.45	8.09
30	18.87	20.91	10.81	18.84	20.83	10.56	18.95	20.99	10.77	18.92	20.95	10.73
40	14.96	16.25	8.62	14.93	16.13	8.04	15.02	16.28	8.39	14.99	16.27	8.54
50	12.51	13.61	8.79	12.48	13.56	8.65	12.56	13.71	9.16	12.53	13.65	8.94
60	10.83	11.59	7.02	10.81	11.52	6.57	10.87	11.65	7.18	10.85	11.62	7.10
70	9.59	10.35	7.92	9.58	10.33	7.83	9.63	10.44	8.41	9.61	10.39	8.12
80	8.65	9.36	8.21	8.64	9.32	7.87	8.69	9.42	8.40	8.67	9.40	8.42
90	7.91	7.55	4.55	7.90	7.53	4.68	7.94	7.62	4.03	7.92	7.58	4.29
100	7.31	7.09	3.01	7.30	7.05	3.42	7.34	7.11	3.13	7.33	7.10	3.14
125	6.21	5.76	7.24	6.20	5.75	7.26	6.24	5.79	7.21	6.23	5.77	7.38
150	5.46	5.03	7.88	5.45	5.01	8.07	5.48	5.07	7.48	5.47	5.05	7.68
175	4.91	4.66	5.09	4.90	4.64	5.31	4.93	4.68	5.07	4.92	4.67	5.08
200	4.50	4.37	2.89	4.49	4.35	3.12	4.52	4.39	2.88	4.51	4.38	2.89
225	4.18	3.98	4.78	4.17	3.96	5.04	4.19	3.98	5.01	4.18	3.98	4.78
250	3.92	3.68	6.12	3.91	3.66	6.39	3.93	3.70	5.85	3.92	3.68	6.12
275	3.70	3.31	10.54	3.69	3.29	10.84	3.72	3.35	9.95	3.71	3.33	10.24
300	3.52	3.07	12.78	3.51	3.06	12.82	3.54	3.09	12.71	3.53	3.08	12.75
350	3.24	2.82	12.96	3.24	2.82	12.96	3.26	2.85	12.58	3.25	2.84	12.62

Table 3: Showing the proton energy in MeV and the stopping power for values for Skeleton-cortical-bone and Skin in MeV/g/cm^2. Here %T represents the percentage difference of this work values from SRIM stopping power.

Energy (MeV)	Stopping power in MeV/g/cm^2 for Skeleton-cortical-bone (child)			Stopping power in MeV/g/cm^2 for Skeleton-cortical-bone (adult)			Stopping power in MeV/g/cm^2 for Skin (child)			Stopping power in MeV/g/cm^2 for Skin (adult)		
	SRIM	This work	%T	SRIM	This work	%T	SRIM	This work	%T	SRIM	This work	%T
1	214.26	242.67	13.26	211.26	236.37	11.89	250.00	281.88	12.75	251.80	284.31	12.91
2	138.49	160.13	15.63	136.49	155.51	13.94	162.91	188.69	15.82	163.21	190.20	16.54
3	102.76	117.38	14.23	101.46	115.44	13.78	119.78	137.81	15.05	119.98	139.42	16.20
4	82.73	90.45	9.33	81.66	88.96	8.94	95.75	106.79	11.53	95.87	108.10	12.76
5	69.72	75.76	8.66	68.85	74.79	8.63	80.33	85.57	6.52	80.42	87.25	8.49
6	60.52	65.13	7.62	59.79	64.36	7.64	69.51	74.17	6.70	69.58	75.69	8.78
7	53.66	58.21	8.48	53.02	57.63	8.69	61.46	66.23	7.76	61.53	67.19	9.20

8	48.32	52.32	8.28	47.75	51.48	7.81	55.21	59.51	7.79	55.28	60.28	9.04
9	44.01	48.19	9.50	43.51	46.86	7.70	50.22	52.99	5.52	50.28	53.36	6.13
10	40.49	43.11	6.47	40.02	42.72	6.75	46.12	48.19	4.49	46.18	48.43	4.87
20	23.23	25.68	10.55	22.99	25.04	8.92	26.23	28.35	8.08	26.29	28.56	8.63
30	16.77	18.09	7.87	16.60	17.85	7.53	18.85	20.86	10.66	18.91	21.07	11.42
40	13.32	14.76	10.81	13.19	14.48	9.78	14.94	16.16	8.17	14.99	16.38	9.27
50	10.35	11.41	10.24	11.04	11.79	6.79	12.49	13.59	8.81	12.54	13.75	9.65
60	9.67	10.49	8.48	9.58	10.24	6.89	10.82	11.55	6.75	10.87	11.69	7.54
70	8.58	9.13	6.41	8.50	8.93	5.06	9.58	10.34	7.93	9.58	10.34	7.93
80	7.75	8.17	5.42	7.68	8.02	4.43	8.64	9.32	7.87	8.65	9.35	8.09
90	7.09	7.34	3.53	7.02	7.06	0.57	7.90	7.53	4.68	7.90	7.53	4.68
100	6.55	6.67	1.83	6.49	6.59	1.54	7.30	7.05	3.42	7.30	7.06	3.29
125	5.58	5.63	0.90	5.52	5.49	0.54	6.20	5.75	7.26	6.20	5.75	7.26
150	4.90	4.84	1.22	4.86	4.70	3.29	5.45	5.01	8.07	5.45	5.01	8.07
175	4.42	4.27	3.39	4.38	4.21	3.88	4.91	4.64	5.50	4.91	4.64	5.50
200	4.05	3.91	3.46	4.01	3.82	4.74	4.49	4.35	3.12	4.49	4.35	3.12
225	3.76	3.57	5.05	3.72	3.51	5.65	4.17	3.96	5.04	4.17	3.96	5.04
250	3.53	3.31	6.23	3.49	3.25	0.86	3.91	3.66	6.40	3.91	3.66	6.39
275	7 33	3.11	6.61	3.30	3.06	7.27	3.70	3.29	11.08	3.70	3.29	11.08
300	3.17	2.92	7.89	3.15	2.87	8.89	3.52	3.06	13.07	3.52	3.06	13.07
350	2.92	2.61	10.62	2.90	2.58	11.03	3.24	2.82	13.96	3.24	2.82	13.96

Table 4: Proton range in cm for Blood (child and adult) and Brain (child and adult) for proton energy 1MeV to 350MeV. Here %T represents the percentage difference of this work values from SRIM range.

Energy (MeV)	Blood (child) (cm)			Blood (adult) (cm)			Brain (child) (cm)			Brain (adult) (cm)		
	SRIM	This work	%T	SRIM	This work	%T	SRIM	This work	%T	SRIM	This work	%T
1	0.00427	0.00377	11.71	0.00423	0.00379	10.40	0.00399	0.00364	8.77	0.00414	0.00365	11.84
2	0.00655	0.00564	13.89	0.00649	0.00567	12.63	0.00628	0.00541	13.85	0.00635	0.00547	13.86
3	0.01783	0.01548	13.18	0.01767	0.01554	12.05	0.01709	0.01477	13.58	0.01729	0.01494	13.59
4	0.03346	0.02979	10.97	0.03315	0.03008	9.26	0.03209	0.02851	11.16	0.03245	0.02883	11.16
5	0.05320	0.04960	6.77	0.03952	0.05005	6.64	0.05101	0.04765	6.59	0.05159	0.04817	6.63
6	0.07684	0.07151	6.94	0.07613	0.07227	5.07	0.07370	0.06861	6.91	0.07454	0.06938	6.92
7	0.10428	0.09670	7.27	0.10331	0.09706	6.05	0.10003	0.09252	7.51	0.10115	0.09379	7.28
8	0.13543	0.12565	7.22	0.13417	0.12600	6.09	0.12990	0.12002	7.61	0.13138	0.12157	7.47
9	0.17021	0.16084	5.50	0.16862	0.16178	4.06	0.16323	0.15453	5.33	0.16511	0.15642	5.26
10	0.20847	0.19889	4.60	0.20653	0.20012	3.10	0.19995	0.19101	4.47	0.20219	0.19310	4.50
20	0.77417	0.71635	7.47	0.76694	0.71888	6.27	0.74241	0.68125	8.24	0.75076	0.69456	7.49
30	1.64440	1.48398	9.76	1.62904	1.48967	8.56	1.57625	1.42305	9.72	1.59408	1.43961	9.69
40	2.78943	2.56800	7.94	2.76336	2.58710	6.38	2.67443	2.46744	7.74	2.70580	2.49293	7.87
50	4.19104	3.85231	8.08	4.15187	3.86651	6.87	4.01831	3.68125	8.39	4.06703	3.73333	8.21
60	5.82917	5.44693	6.56	5.77469	5.48003	5.10	5.59061	5.21630	6.70	5.65529	5.28055	6.63
70	7.69864	7.13334	7.34	7.62669	7.14714	6.29	7.38006	6.80747	7.76	7.46722	6.90664	7.51
80	9.77224	9.03098	7.59	9.68092	9.06974	6.31	9.36363	8.63800	7.75	9.47635	8.74042	7.77
90	12.0392	12.6132	4.77	11.9267	12.6467	6.04	11.5453	12.0301	4.20	11.6808	12.2111	4.54
100	14.4911	14.9407	3.10	14.3557	15.0255	4.67	13.8928	14.3417	3.23	14.0464	14.5014	3.24
125	21.3655	23.0347	7.81	21.1659	23.0748	9.02	20.4679	22.0578	7.77	20.6998	22.3501	7.97
150	29.1996	31.6958	8.55	28.9267	31.8224	10.01	28.0055	30.2702	8.09	28.3291	30.6851	8.32
175	37.9185	39.9527	5.36	37.5615	40.1250	6.82	36.3529	38.2949	5.34	36.7805	38.7495	5.35
200	47.3178	48.7254	2.97	46.8756	48.9494	4.42	45.3473	46.6902	2.96	45.8891	47.2511	2.97
225	57.3397	60.2211	5.03	56.8038	60.5252	6.55	55.0644	57.9698	5.28	55.7321	58.5327	5.03
250	67.9668	72.3994	6.52	67.3316	72.7951	8.11	65.2595	69.3162	6.22	66.0612	70.3696	6.52
275	79.2378	88.5740	11.78	78.4973	89.1124	13.52	75.8656	84.2448	11.04	76.8086	85.5736	11.41
300	90.8890	104.211	14.66	90.0398	104.552	16.12	86.9972	99.6667	14.56	88.0907	100.961	14.61

350	115.256	132.422	14.89	114.179	132.421	16.98	110.267	126.129	14.69	111.680	127.803	14.84

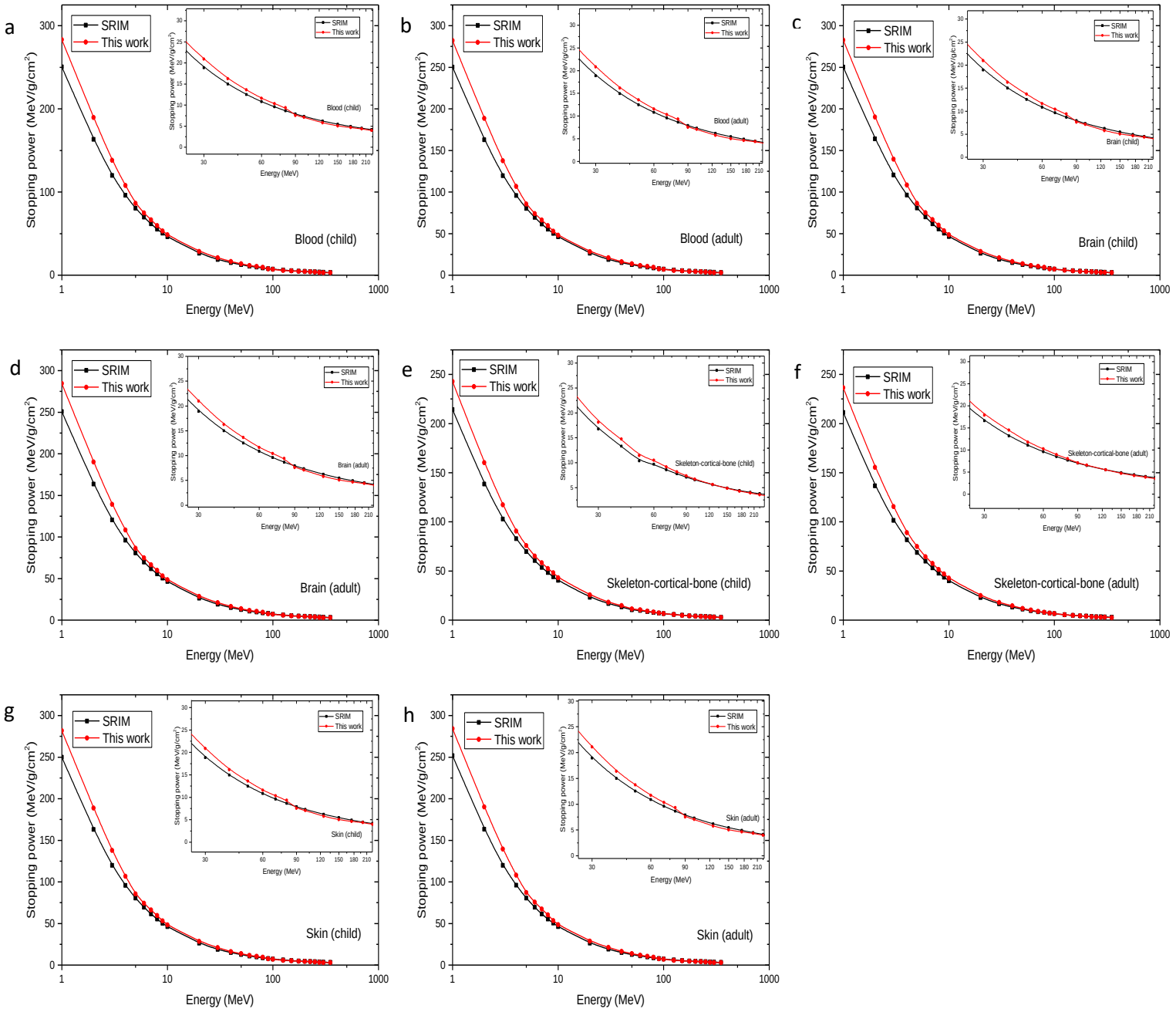

Fig.1 a) The stopping power of blood (child) as a function of proton energy. b) The stopping power of blood (adult) as a function of proton energy. c) The stopping power of brain (child) as a function of proton's energy. d) The stopping power of blood (adult) as a function of proton's energy. e) The stopping power of skeleton-cortical-bone (child) as a function of proton's energy. f) The stopping power of skeleton-cortical-bone (adult) as a function of proton's energy. g) The stopping power of skin (child) as a function of proton's energy. h) The stopping power of skin (adult) as a function of proton's energy.

Table 4: Proton range in cm for Blood (child and adult) and Brain (child and adult) for proton energy 1MeV to 350MeV. Here %T represents the percentage difference of this work values from SRIM range

Energy (MeV)	Blood (child) (cm)			Blood (adult) (cm)			Brain (child) (cm)			Brain (adult) (cm)		
	SRIM	This work	%T	SRIM	This work	%T	SRIM	This work	%T	SRIM	This work	%T
1	0.00427	0.00377	11.71	0.00423	0.00379	10.40	0.00399	0.00364	8.77	0.00414	0.00365	11.84
2	0.00655	0.00564	13.89	0.00649	0.00567	12.63	0.00628	0.00541	13.85	0.00635	0.00547	13.86
3	0.01783	0.01548	13.18	0.01767	0.01554	12.05	0.01709	0.01477	13.58	0.01729	0.01494	13.59
4	0.03346	0.02979	10.97	0.03315	0.03008	9.26	0.03209	0.02851	11.16	0.03245	0.02883	11.16
5	0.05320	0.04960	6.77	0.03952	0.05005	6.64	0.05101	0.04765	6.59	0.05159	0.04817	6.63
6	0.07684	0.07151	6.94	0.07613	0.07227	5.07	0.07370	0.06861	6.91	0.07454	0.06938	6.92
7	0.10428	0.09670	7.27	0.10331	0.09706	6.05	0.10003	0.09252	7.51	0.10115	0.09379	7.28
8	0.13543	0.12565	7.22	0.13417	0.12600	6.09	0.12990	0.12002	7.61	0.13138	0.12157	7.47
9	0.17021	0.16084	5.50	0.16862	0.16178	4.06	0.16323	0.15453	5.33	0.16511	0.15642	5.26
10	0.20847	0.19889	4.60	0.20653	0.20012	3.10	0.19995	0.19101	4.47	0.20219	0.19310	4.50
20	0.77417	0.71635	7.47	0.76694	0.71888	6.27	0.74241	0.68125	8.24	0.75076	0.69456	7.49
30	1.64440	1.48398	9.76	1.62904	1.48967	8.56	1.57625	1.42305	9.72	1.59408	1.43961	9.69
40	2.78943	2.56800	7.94	2.76336	2.58710	6.38	2.67443	2.46744	7.74	2.70580	2.49293	7.87
50	4.19104	3.85231	8.08	4.15187	3.86651	6.87	4.01831	3.68125	8.39	4.06703	3.73333	8.21
60	5.82917	5.44693	6.56	5.77469	5.48003	5.10	5.59061	5.21630	6.70	5.65529	5.28055	6.63
70	7.69864	7.13334	7.34	7.62669	7.14714	6.29	7.38006	6.80747	7.76	7.46722	6.90664	7.51
80	9.77224	9.03098	7.59	9.68092	9.06974	6.31	9.36363	8.63800	7.75	9.47635	8.74042	7.77
90	12.0392	12.6132	4.77	11.9267	12.6467	6.04	11.5453	12.0301	4.20	11.6808	12.2111	4.54
100	14.4911	14.9407	3.10	14.3557	15.0255	4.67	13.8928	14.3417	3.23	14.0464	14.5014	3.24
125	21.3655	23.0347	7.81	21.1659	23.0748	9.02	20.4679	22.0578	7.77	20.6998	22.3501	7.97
150	29.1996	31.6958	8.55	28.9267	31.8224	10.01	28.0055	30.2702	8.09	28.3291	30.6851	8.32
175	37.9185	39.9527	5.36	37.5615	40.1250	6.82	36.3529	38.2949	5.34	36.7805	38.7495	5.35
200	47.3178	48.7254	2.97	46.8756	48.9494	4.42	45.3473	46.6902	2.96	45.8891	47.2511	2.97
225	57.3397	60.2211	5.03	56.8038	60.5252	6.55	55.0644	57.9698	5.28	55.7321	58.5327	5.03
250	67.9668	72.3994	6.52	67.3316	72.7951	8.11	65.2595	69.3162	6.22	66.0612	70.3696	6.52
275	79.2378	88.5740	11.78	78.4973	89.1124	13.52	75.8656	84.2448	11.04	76.8086	85.5736	11.41
300	90.8890	104.211	14.66	90.0398	104.552	16.12	86.9972	99.6667	14.56	88.0907	100.961	14.61
350	115.256	132.422	14.89	114.179	132.421	16.98	110.267	126.129	14.69	111.680	127.803	14.84

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Table 5: Proton range in cm for Skeleton-cortical-bone (child and adult) and Skin (child and adult) for proton energy 1MeV to 350MeV. Here %T represents the percentage difference of this work values from SRIM range

Energy (MeV)	Skeleton-cortical-bone (child) (cm)			Skeleton-cortical-bone (adult) (cm)			Skin (child) (cm)			Skin (adult) (cm)		
	SRIM	This work	%T	SRIM	This work	%T	SRIM	This work	%T	SRIM	This work	%T
1	0.00854	0.00754	11.71	0.00908	0.00812	10.57	0.00420	0.00355	15.48	0.00432	0.00357	17.36
2	0.01321	0.01142	13.55	0.01406	0.01234	12.23	0.00644	0.00556	13.66	0.00667	0.00573	14.09
3	0.03561	0.03118	12.44	0.03784	0.03326	12.10	0.01753	0.01524	13.06	0.01817	0.01563	13.98
4	0.06636	0.06069	8.54	0.07053	0.06474	8.21	0.03289	0.02950	10.31	0.03410	0.03024	11.32
5	0.10499	0.09662	7.97	0.11154	0.10268	7.94	0.05228	0.04908	6.12	0.05422	0.04997	7.84
6	0.15118	0.14048	7.08	0.16056	0.14916	7.10	0.07552	0.07078	6.28	0.07832	0.07200	8.07
7	0.20462	0.18862	7.82	0.21727	0.19989	8.00	0.10250	0.09513	7.19	0.10629	0.09733	8.43
8	0.26510	0.24483	7.65	0.28146	0.26107	7.24	0.13312	0.15852	9.08	0.15775	0.12657	9.77
9	0.33265	0.30379	8.68	0.35302	0.32778	7.15	0.16726	0.17430	4.21	0.19511	0.16341	6.25
10	0.40676	0.38204	6.08	0.43178	0.40449	6.32	0.20490	0.19610	4.29	0.21242	0.20256	4.64
20	1.49678	1.35397	9.54	1.58677	1.45686	8.19	0.76057	0.70370	7.48	0.78775	0.72514	7.95
30	3.16457	2.93366	7.30	3.35421	3.11932	7.00	1.61538	1.45974	9.63	1.67160	1.50023	9.25
40	5.35810	4.83536	9.76	5.67702	5.17127	8.91	2.74096	2.53403	7.55	2.83588	2.59523	8.49
50	8.66378	7.85889	9.29	8.48331	7.97964	5.94	4.11929	3.78587	8.09	4.25917	3.88436	8.80
60	11.1655	10.2926	7.82	11.8246	11.0625	6.45	5.72550	5.36363	6.32	5.91628	5.50128	7.01
70	14.7168	13.8302	6.02	15.5859	14.8353	4.82	7.56263	7.00677	7.35	7.85072	7.27369	7.35
80	18.6542	17.6952	5.14	19.7500	18.9127	4.24	9.60068	8.90021	7.30	9.95490	9.20962	7.49
90	22.9718	22.1894	3.41	24.3419	24.2039	0.57	11.8291	12.4103	4.91	12.2797	12.8831	4.91
100	27.6595	27.1619	1.80	29.2881	28.8437	1.52	14.2397	14.7447	3.55	14.7822	15.2847	3.40
125	40.6667	40.3055	0.89	43.1304	43.3661	0.55	21.0000	22.6435	7.83	21.8000	23.5060	7.83
150	55.6469	56.3367	1.24	58.8642	60.8681	3.40	28.7064	31.2275	8.78	29.8000	32.4172	8.78
175	72.0407	74.5714	3.51	76.2740	79.3539	4.04	37.2098	39.3750	5.82	38.6273	40.8750	5.81
200	89.9185	93.1381	3.58	95.2818	100.021	4.97	46.5367	48.0345	3.22	48.3098	49.8643	3.22
225	109.021	114.823	5.32	115.613	122.529	5.98	56.4029	59.3939	5.30	58.5516	61.6566	5.31
250	129.085	137.665	6.65	136.986	147.102	7.38	66.8670	71.4344	6.83	69.4143	74.1557	6.84
275	150.577	161.228	7.07	159.418	171.922	7.84	77.7568	87.4468	12.46	80.7189	90.7781	11.86
300	172.609	187.387	8.56	182.248	200.028	9.76	89.1903	102.598	15.03	95.5881	106.506	13.42
350	218.723	244.701	11.88	231.062	259.721	12.4	113.102	129.947	15.89	117.411	134.897	14.90

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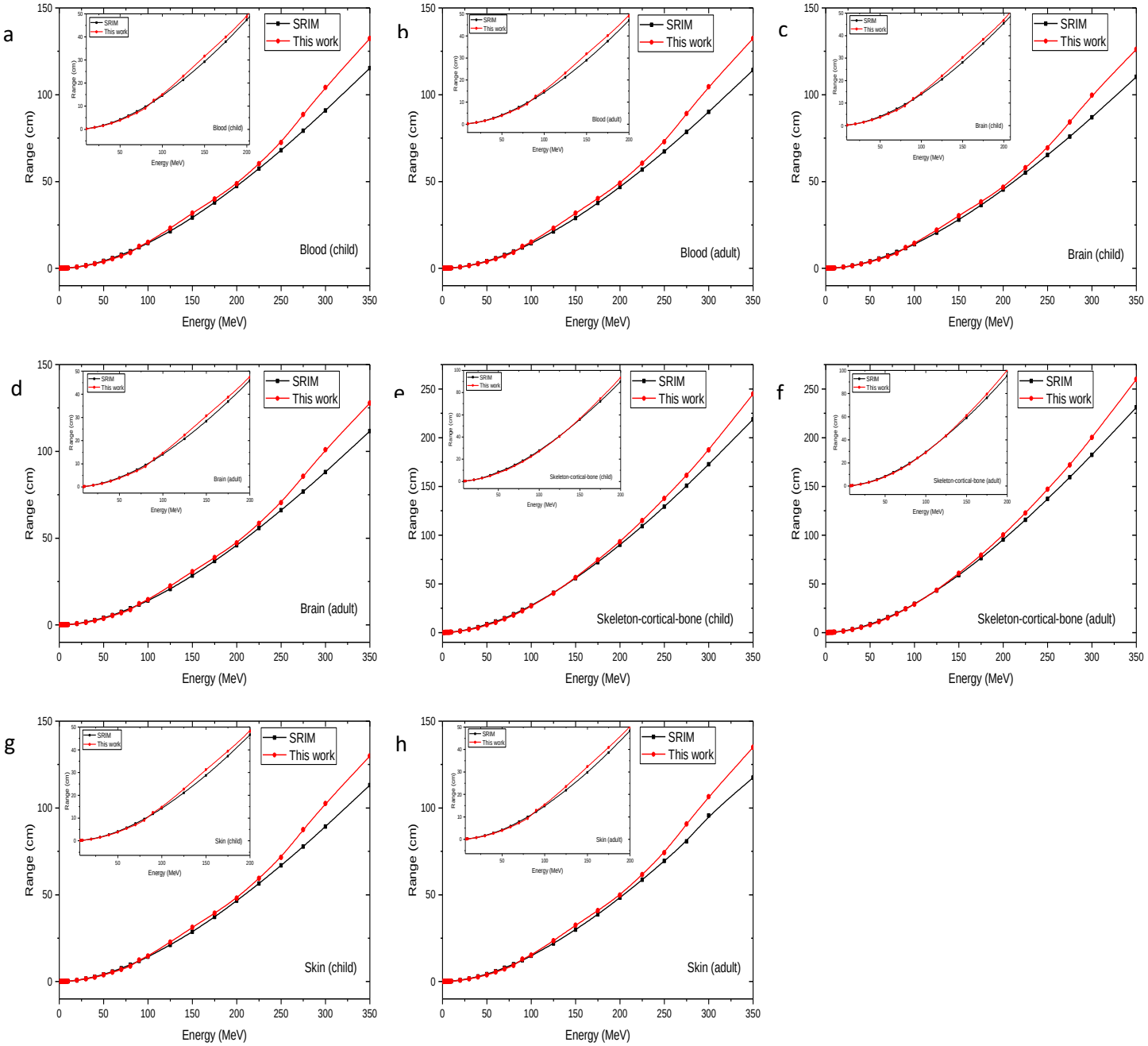

Fig.2 a) The CSDA ranges of proton in blood (child) tissue. b) The CSDA ranges of proton in blood (adult) tissue. c) The CSDA ranges of proton in brain (child) tissue. d) The CSDA ranges of proton in brain (adult) tissue. e) The CSDA ranges of proton in skeleton-cortical-bone (child) tissue. f) The CSDA ranges of proton in skeleton-cortical-bone (adult) tissue. g) The CSDA ranges of proton in skin (child) tissue. h) The CSDA ranges of proton in skin (adult) tissue.

2.2 Calculation of range

The path length of proton is almost straight line. That's why Monte Carlo method, which is based on a broad class of computational algorithms, has been using in a successful manner. The range of proton can be calculated by numerical integration method. Another method for the calculation of proton range is CSDA (Continuous Slowing Down Approximation) method and we employed this method in this work. Incident particle continuously losses its energy and CSDA method neglects this energy loss fluctuations. The range R for an incident proton in the CSDA method is given as:

$$R = \rho \int_{E_f}^{E_0} \frac{dE}{S(E)} \quad (8)$$

Where,

E_o= initial energy of incident charged particle in material,

E_f= final energy of incident charged particle in material.

3. Results and discussion

Aging is a continuous process of natural change that brings about many changes in the fundamental compositions of most soft and hard body tissues. It is generally agreed that genetics, state of health, sex, disease, physical activity, metabolism, nutrition are the main factors affecting the body compositions. Due to this reason, we collected human body compositions data (Table-1) for both child and adult to show how they are affecting the SP and range of proton energy.

Using equation (3) we calculated the SP of protons with energy (1-350MeV) on blood, brain, skeleton-cortical-bone, and skin for both child and adult and compared with the values obtained from the SRIM code. Various works on SP and range of proton efficiently showed that SRIM code was the best fit with their values in terms of other programs. So, the percentage difference of our theoretical work has been compared with the values of SRIM code in Table 2 and Table 3 and also illustrated graphically in Fig.1. From Table 2 and Table 3, the total percentage difference between SRIM and this work are 8.40%, 8.24%, 8.38%, 8.41%, 7.57%, 6.91%, 8.31%, 8.85% respectively for blood (child), blood (adult), brain (child), brain (adult), skeleton-cortical-bone (child), skeleton-cortical-bone (adult), skin (child), skin (adult). The percentage difference rate for all tissues is less than 10%, which shows that our results are in a good agreement with SRIM. From equation (3), SP is proportional to z^2 and inversely proportional to v^2. The SP increases rapidly at low energies of proton and gradually decreases with the increase of proton energy. In Fig. 1, the difference between this work values and SRIM values at energies ranging from (1-10) MeV is quite high but there is almost no difference at energies ranging from (80-350) MeV. Because when proton enters in the target tissue, they start to interact with many electrons and in this encounter proton transfer energy mostly by excitation and ionization. So, SP decreases as the proton velocity increases.

By using equation (8) we have obtained the CSDA ranges of the proton at energies ranging from (1-350MeV) and compared with the SRIM code. Results are tabulated in Table 4 and Table 5 and also illustrated graphically proton range in cm vs. proton energy in MeV in Fig. 2. From Table 4 and Table 5, the total percentage difference between SRIM and this work are 8.15%, 7.94%, 8.04%, 8.14%, 7.15%, 6.82%, 8.32%, 8.73% respectively for blood (child), blood (adult), brain (child), brain (adult), skeleton-cortical-bone (child), skeleton-cortical-bone (adult), skin (child), skin (adult). The percentage difference rate for all tissues is less than 10% which shows that our results are in a good agreement with SRIM. At 250 MeV or above the percentage difference starts to increase rapidly. When the CSDA method is applied at high energies, protons tend to pick up electrons from the target tissues which will give rise to linear energy loss and deviations. This is the severe limitation of the CSDA method and so, we calculated the range of proton up to 350 MeV. In Fig. 2, this work shows the best fit with SRIM at energy range of (5-250MeV) and vary almost linearly with these energies. The rise of the curve starts so rapidly beyond 250 MeV and demolished this linearity. The first reason behind this rapid rise is due to increasing bremsstrahlung probability and the other reason is the CSDA method which is discussed above.

4. Conclusion

In this work, we have done the SP and range calculations for protons incident on the 4 different human tissues (blood, brain, skeleton-cortical-bone, skin) of both child and adult. Though aging brings many changes in the fundamental compositions of most tissues, we got little difference between child and adult values of SP and range. Furthermore, it is observed from these tables that our results are in a good agreement with SRIM, especially at the

energy range 50-250 MeV and this energy interval is essential at the proton therapy. In addition, that shows the effectiveness and reliability of this study. Because the stability of this work starts to break beyond 250MeV, more research should be conducted in order to improve the accuracy of computation in the SP and range values.

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