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Nuclear energy loss and range of heavy ions in SiO2, LiF and Kapton polyatomic targets: A Monte Carlo study

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Introduction

The energy loss of ions in amorphous targets has been investigated mainly in the low, intermediate and high ion energy.

There is a long-standing of interest in stopping powers for heavy charged particles in matter, because such information is needed in many areas of basic and applied physics such as: Radiological physics and biomedical dosimetry

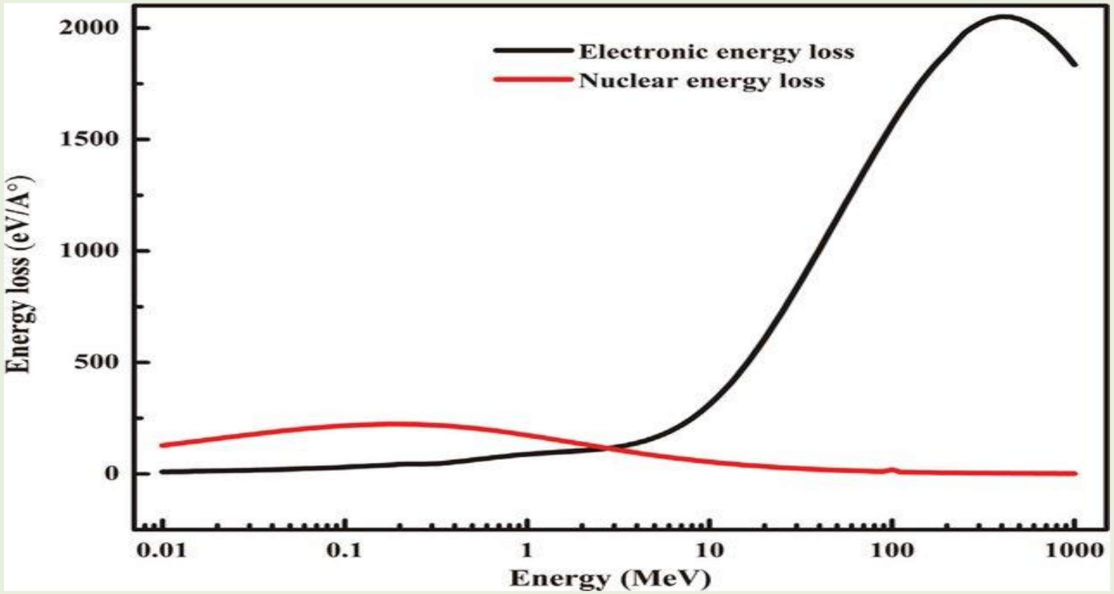
The Monte Carlo simulation has many numbers of advantages over present analytical formulation based on transport theory.

The calculation method is very flexible; it allows us to vary risk assumptions under all parameters and thus model a range of possible outcomes.

Nuclear stopping power

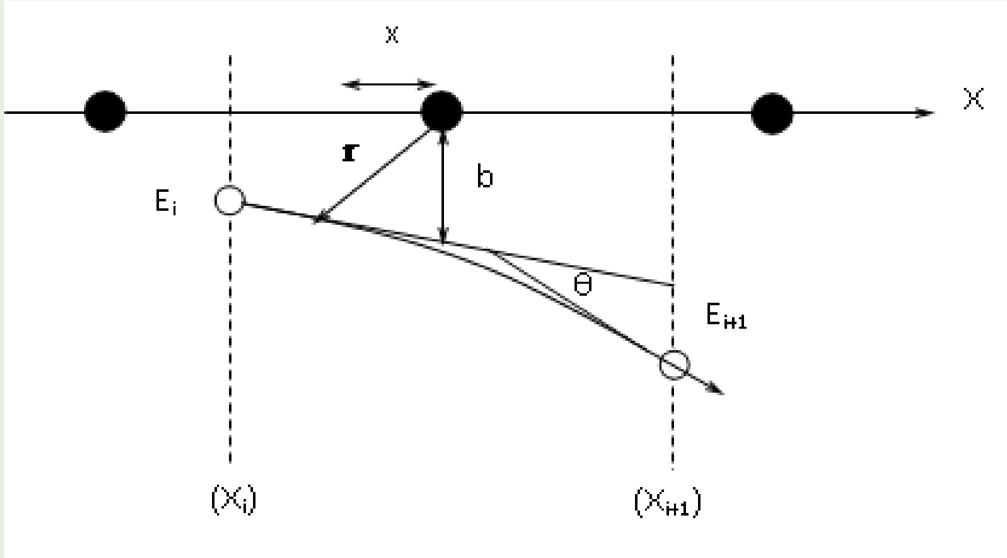
At lower energies, the slowing down of ions is traditionally separated into two distinct processes: electronic and nuclear slowing down or stopping power. The sum of these two processes is called the total stopping power.

$$S(E) = S_e(E) + S_n(E)$$



Ratio between nuclear and electronic stopping power

The particle is assumed to change direction as a result of binary collisions and to move in a straight path between two consecutive collisions.



Schematic collision between ions and target

The energy transfer T to the target atom in a single collision is determined from:

$$T = \frac{4M_1M_2}{(M_1+M_2)^2} E sin^2\left(\frac{\theta}{2}\right) = \gamma E sin^2\left(\frac{\theta}{2}\right)$$

The mean energy-loss per unit path due to elastic collisions is given by

$$\left(-\frac{dE}{dx}\right)_n = N\int_0^{\infty} T(b)d\sigma = NS_n(E)$$

Where N is the atomic density of the target, Sn is the nuclear stopping cross-section, b is the impact parameter and σ is the scattering cross section.

The mean range can be simply obtained by the integration of the nuclear stopping power

$$R(E) = \int_0^{E} \frac{dE'}{NS_n(E')}$$

Calculation method

Each incident ion is characterized by its atomic number, its atomic mass, its energy, its direction, and its space position.

The target is considered amorphous with atoms at random locations and the directional properties applicable for a crystalline material are ignored.

$$< T > = \int T(b) d\sigma$$

The distance travelled between collisions, we can use the free flight path length dl becomes

$$dl = -\frac{1}{N\sigma} \ln(\xi)$$

The mean range R is obtained by using this expression:

$$R = \int < cos\theta > dl$$

The initial direction is specified by the directional cosines using the beam trajectory as the x-axis:

$$\theta = cos^{-1}(1 - 2\xi')$$

The azimuthal scattering angle ϕ is randomly calculated in the range [0, 2π], selected using the relation:

$$\phi = 2\pi\xi''$$

The calculations are treated by the application of computer simulation technique. The random number is given by using a subroutine to generate the number ξ. The program simulates the trajectories of the incidental particle in the matter, with the assistance of the random procedure

Results

The results of the calculation using the Monte Carlo simulation are shown in figures 1, 2 and 3. These figures show the variation of the nuclear energy loss by as a function of the incident particle energy. This study was carried out for helium in SiO2, LiF and Kapton at energies from 0.01 keV to 10 MeV.

Our results were found to be in excellent agreement with those obtained by SRIM code and PSTAR/ASTAR.

Fig. 1

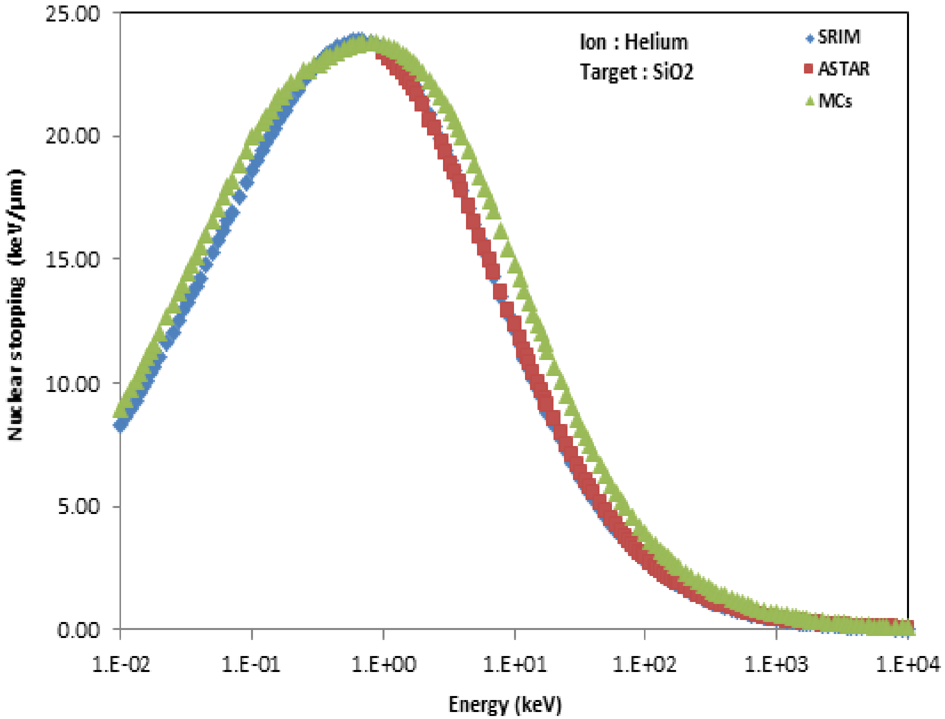


Fig.2

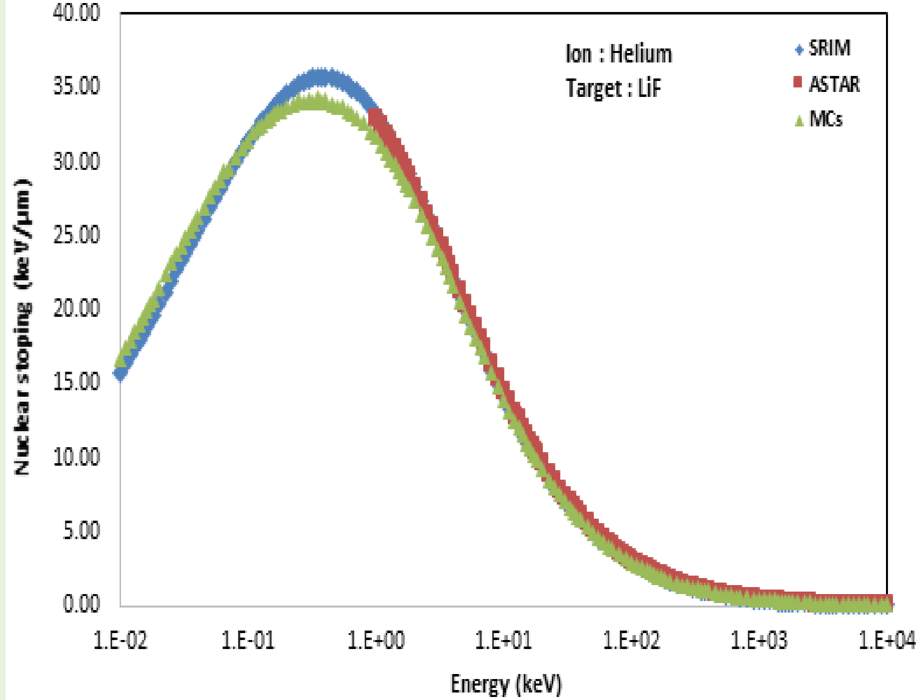
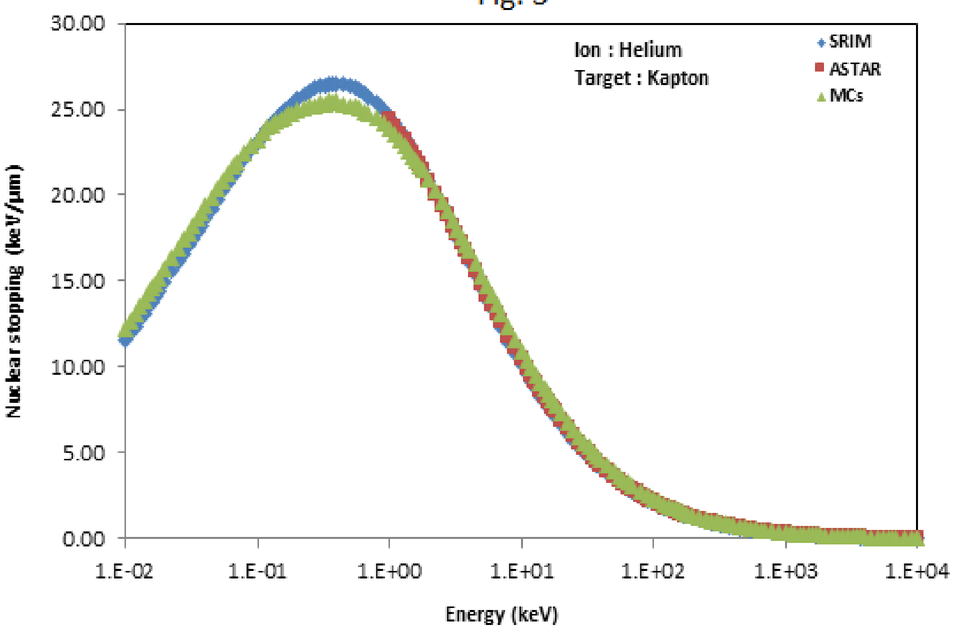


Fig. 3



Nuclear stopping power behaviour in the energy range of interest for helium particles in SiO_2 (1), LiF (2) and (3) Kapton

Figures. 4, 5 and 6 shows the behaviour of nuclear energy loss versus of kinetic energy for 11B in SiO2, 14N in LiF and 58Ni in Kapton. All curves of the nuclear stopping increase when increasing the incident energy until a maximum, and then decreases as the energy of the ion increases.

These results showed that the contribution, of atomic number of incident heavy ions is important on a nuclear energy loss. This is probably due to the fact that when the number of incident particles is increased, the number of interactions increases, which leads to an increase in the energy lost.

Fig. 4

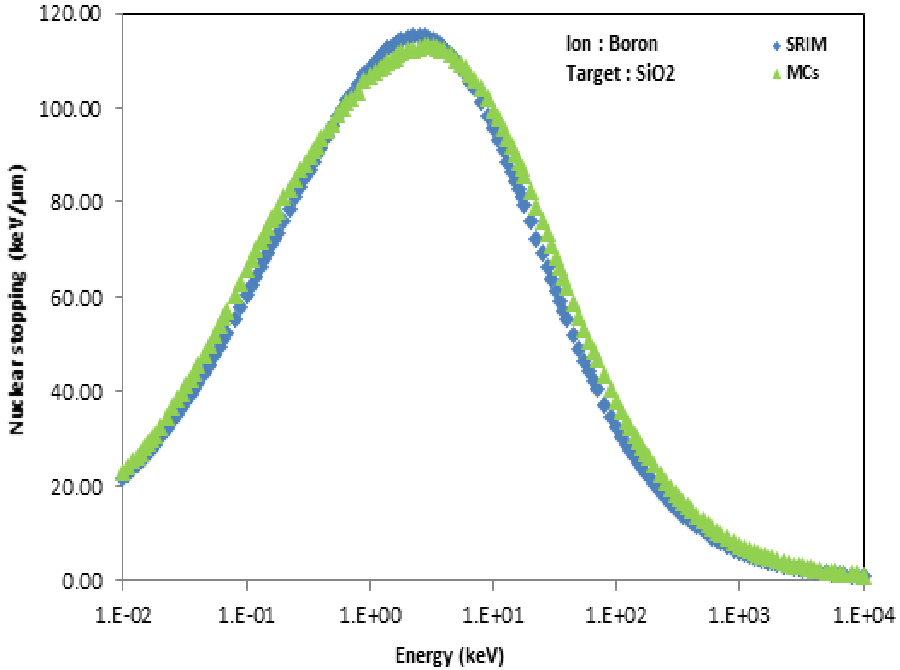


Fig. 5

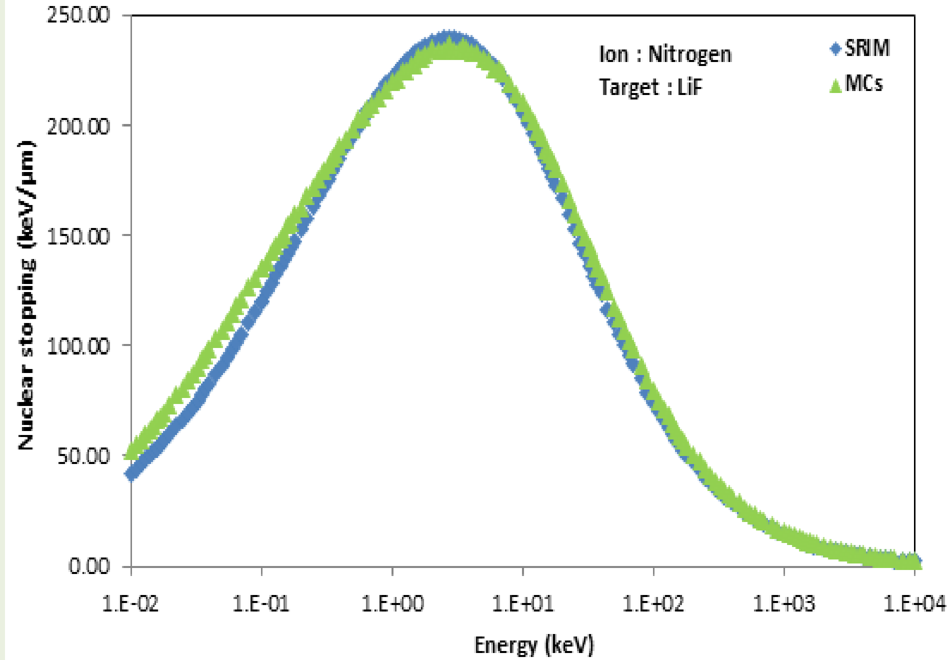
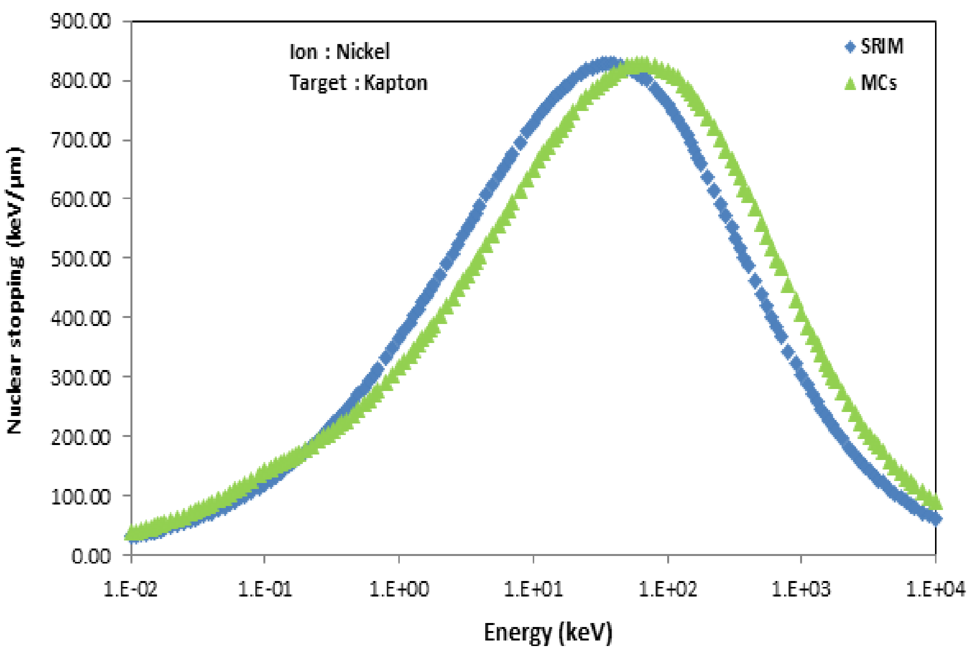


Fig. 6



Nuclear stopping power behaviour in the energy range of interest for ^{11}B in SiO2 (4), ^{14}N in LiF (5) and ^{58}Ni in Kapton (6).

Comparison of experimental and calculated range for ions Au and Bi in SiO_2.

Energy (keV)	Range (Å)							
	Au				Bi			
	Exp. [27]	SRIM	Other calc. [28]	Present work	Exp. [27]	SRIM	Other calc. [28]	Present work
10	---	116		120	94	118	135	112
15	135	143	162	141	112	144	166	123
20	142	166	187	152	140	167	191	155
30	200	207	234	205	185	207	238	192
50	315	278	313	317	260	277	316	271
70	365	341	382	374	345	339	386	351
100	469	428	481	473	395	425	483	403
150	---	562	---	581	---	555	---	578
200	700	688	773	708	655	677	770	667
250	---	810	---	837		794	---	826
300	---	928	---	958		908	---	931
350	---	1044	---	1081		1020	---	1038
400	1230	1159	1310	1243	1150	1129	1290	1163

Conclusions

In order to study the nuclear stopping power, we carried out by the calculations using the Monte Carlo method on the SiO_2, LiF and Kapton materials.

In the range of our energies and materials, our results are in excellent agreement with those found the SRIM code, the PSTAR and ASTAR. (a very small discrepancies, less than 5%).

The corresponding behaviour of the nuclear stopping of the amorphous targets increases when increasing the incident kinetic energy until a maximum value and then decreases. The maximum of nuclear energy loss increases with increasing the atomic number of incident particle.

The contribution of the nuclear stopping power to the total stopping cross section is dominant only at low energy.

Its significance in the theory of radiation effects, such as radiation damage and the relation between mean range and total range, makes the study of nuclear collisions important.

The heavy ion mean ranges in amorphous target SiO2, have been also calculated by using a Monte Carlo simulation based on the transport theory. Au, and Bi projectiles have been chosen as incident ion.

It is found that the agreement between calculated values on mean range and the experiment is good (less than 5 %).

References

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Thank you very much