The Verification of Monte Carlo Transport Codes

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INTRODUCTION

The Monte Carlo codes for calculating the particle transport and interactions with matter have wide range of applications, including not only calculations of accelerator shielding but also detector design, medical physics, radiobiology, cosmic rays etc. The benchmarking of the codes is needed to be sure that the simulations give reasonable results.

The study was started at GSI in the frame of the FAIR (Facility for Antiproton and Ion Research) project. Series of the experiments with different target materials, target configurations and different projectiles were held at SIS18 synchrotron in Darmstadt. The goal of the study is to find the radioactive nuclide distribution and stopping ranges of the primary projectiles in different materials irradiated by different ions.

This work presents the experimental techniques and some results of the irradiation of aluminum targets by uranium and argon beams at 500 MeV/u. Obtained results are compared with the simulations done using different codes.

SIMULATIONS

The stopping range of the primary ions at 500 MeV/u was found by simulating the experimental setup using FLUKA (2011.2.4), MARS15 and SHIELD-A. This information was used for choosing the thickness of the target and assembling it in an optimal way.

MC Code	Ar^{+18} stopping range ± straggling, mm	U^{+73} stopping range ± straggling, mm
FLUKA	66.50 ± 0.10	15.00 ± 0.10
MARS	68.13 ± 0.11	
SHIELD	65.89 ± 0.05	14.95 ± 0.05

The depth profiles of the residual activity (amount of nuclides) were simulated by dividing the target into many discs and irradiating it by the Gaussian beam of 500 MeV/u. The obtained number of radioactive nuclei at the end of irradiation was normalized per primary projectile and per unit thickness.

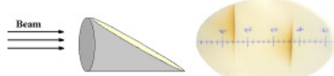
In all the simulations the energy losses in 100 µm stainless steel vacuum window and 1m air gap were taken into account.

EXPERIMENTAL METHOD

Two types of targets were irradiated.

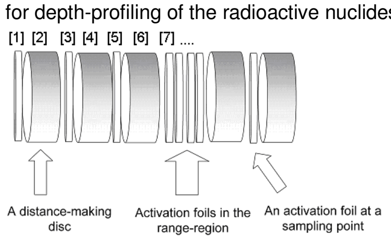
1. The truncated cylinder covered with organic material was used for preliminary estimations of the stopping range.

This technique is based on the idea, that the darkening of the polymer foil depends on the deposited energy, thus the darkest area would correspond to the maximum of the energy deposition.



Aluminium cylinder irradiated by 500 MeV/u and 950 MeV/u U^{+73} ions.

2. The cylinders assembled from the activation foils and spacers were irradiated for depth-profiling of the radioactive nuclides.

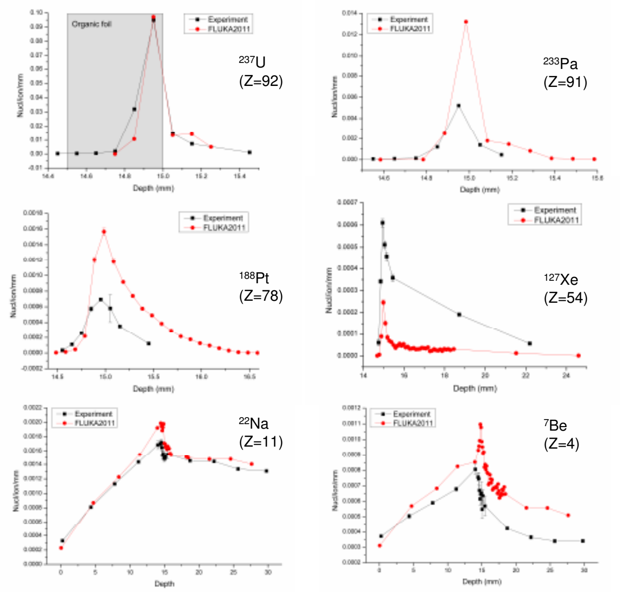


Gamma spectroscopy was performed on all the activation foils to find the types and amount of nuclides in each foil. Gamma-spectra were measured by a high-purity germanium (HPGe) detector after the end of the irradiation.

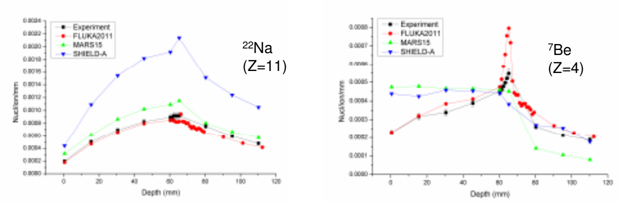
Presented experiments were held at 500 MeV/u. One of the aluminium targets with total thickness ~111 mm was irradiated by $1.01 \cdot 10^{13}$ argon ions. The other target with total thickness ~30mm was irradiated by uranium beam until the total number of projectiles on the target was $5.07 \cdot 10^{11}$ ions.

RESULTS

The resolution of the truncated-cylinder technique for finding the range depends on the configuration of the target. In the experiment with the uranium beam the accuracy of finding the position of the trace was 0.25 mm. As the range of ions at the same initial kinetic energy per nucleon is roughly proportional to A/Z^2, the difference in ranges of ^{238}U and ^{237}U does not exceed 1%, therefore the depth profile of ^{237}U could be used for studying the stopping range of the primary ^{238}U. The following figures present the depth profiles of some of the nuclides, produced by irradiating the aluminium target by uranium beam at 500 MeV/u.



In case of an argon beam of 500 MeV/u there are not as many nuclide species produced in the aluminium target, as in case of uranium beam.



CONCLUSION

- The stopping range of 500 MeV/u uranium ions in aluminum target predicted by FLUKA (2011.2.4) is in a very good agreement with the experiment.
- The amount of ^{237}U is simulated with a good accuracy when the electromagnetic dissociation is taken into account.
- The amount of heavy projectile fragments is overestimated by FLUKA, while the amount of lighter projectile fragments is underestimated.
- FLUKA gives 10% discrepancy simulating the total activity of the identified nuclides in case of uranium beam.
- In case of argon beam FLUKA results are in a good agreement with the experimental ones, while MARS and SHIELD give deviations in the absolute value and in the shape of the depth-profile.
- FLUKA results for the total number of identified nuclides coincides with the experiment within 1%, while MARS and SHIELD give 15% and 80% discrepancies, respectively.