MEASUREMENT OF THE ENERGY DEPOSITION PROFILE FOR ^{238}U IONS WITH ENERGY 500 AND 950 MEV/U IN STAINLESS STEEL AND COPPER TARGETS*

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Abstract

Sub-millimetre wall thickness is foreseen for the vacuum tubes in the magnets of the superconducting dipoles of the SIS100 and SIS300 of the FAIR Project. The Bragg peak of the energy deposition by the U ions in these walls may lie dangerously close to the superconducting cables. Thus the precise knowledge of the dE/dx profile is essential for estimating the heat load by the lost ions in the vicinity of the superconducting wires. Here we present the preliminary results of the measurement of the U ion beam energy deposition profile in Cu and stainless steel targets and compare the measured data with the dE/dx calculations using different codes.

THE 'THICK TARGET' METHOD

The 'thick target' method was used for precision measurement of the total energy deposition by the U ions in solids. The method offers the following advantages [1-3] for our purpose:

- it provides direct measurement of the energy deposition function, rather than its reconstruction from the differential energy deposition measurements using thin foils;
- it eliminates the 'edge effects' (influence of particle entrance to the bulk and its exit from the bulk on the particle energy deposition), as compared to the 'thin foil' approach;
- it takes into account beam straggling and fragmentation, secondary particles, etc.

The method consists in measuring the energy deposited along the ion path in a target of variable thickness which covers the total stopping range (Fig.1)

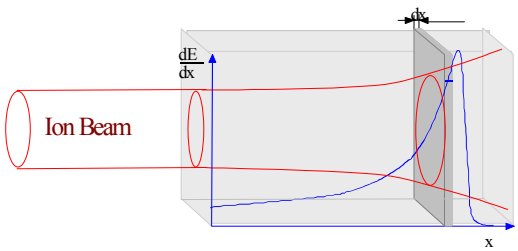

Figure 1: The scheme of the "thick target" method

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In our experiment the target consisted of two wedges, the larger one sliding along the fixed smaller one to vary the target thickness (Fig. 2).

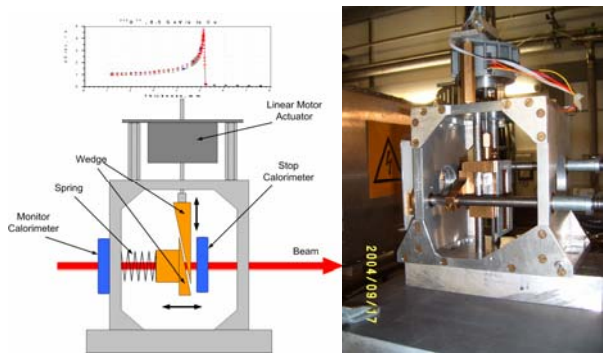

Figure 2: Scheme and photo of the manipulator

Such targets were manufactured of Cu and stainless steel with precise control of the angle (5^0) and surfaces of optical quality. The gap between the two wedges was about ~100μm and the precision of setting the target thickness is determined by the precision of the manipulator moving one of the wedges against the other. The manipulator consisted of the linear motor actuator, the control unit and a PC with software (Fig. 2). The axial resolution of the mounted manipulator was about 50μm, which allowed setting the total thickness of the wedges with a precision of about 2 μm.

The Monitor Calorimeter (shown in blue in Fig.2) provided calibration of the incoming beam intensity (number of ions), while the Stop Calorimeter measured the ion energy deposition.

The calorimeters (Fig.3) measure the change of temperature in a thin layer of material due to its heating by the passing ion beam. They are enclosed in a metal case and consist of a receiving platform made of a foil attached to thermo-modules, which are fixed on a massive thermostat. The foil thickness is selected to be less than 1% of the total stopping range of the ions of interest. The thermostat is isolated from the calorimeter body. The increment of the foil temperature is directly proportional to the energy deposited by the ion beam passing through the calorimeter. Two thermo-elements measure the increment of the foil temperature and transform it to electrical signal. For absolute calibration two thin-film resistances of 0.05 mm thickness are glued to the surface

of the foil out of the direct exposure to the beam. The error of the specific deposited energy measurement is 7%. The size of the device is Ø50x11mm. The aperture of the calorimeter is Ø15 mm. The detector sensitivity is 5mV/J. The amplifier with K=10^4 and the oscilloscope were used to record the signal.

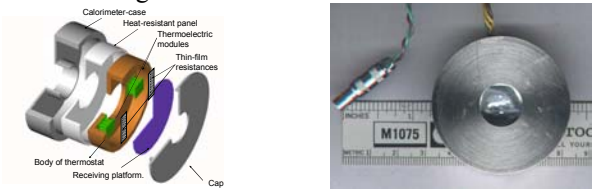

Figure 3: Schematic view and photo of the calorimeter

EXPERIMENTAL RESULTS

The measurements of the dE/dx by the ^{238}U ion beam with energies E = 500 and 950 MeV/u in Cu and stainless steel targets were performed in the Cave A of the experimental area of the SIS-18 facility at GSI Darmstadt during the U-beam run in September 2004. Slow extracted U ions with 100 ms pulse length were focused onto the target on a spot of ∅8mm diameter. The effective registration area of the calorimeter detectors was ~∅15mm, which safely overlaps the beam spot on the target.

The measured experimental curves are shown in Figs.4-7. The experimental error in the range measurement was <4% and consisted of the uncertainty in the ion energy (1%) and the error of the method itself (2.8-3.0%).

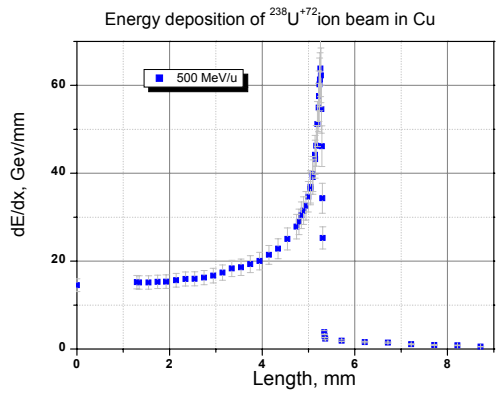

Figure 4: Energy deposition of $^{238}U^{+72}$ ion beam with 500MeV/u energy in Cu

COMPARISON WITH CALCULATIONS

The results of the dE/dx measurements were compared with dE/dx calculations using the ATIMA [5-6], SRIM [7] and SHIELD [8] codes.

All codes except SRIM gave a good agreement (within the error bars of the measurement) with the measured data for the case of U ions of energy E = 500 MeV/u.

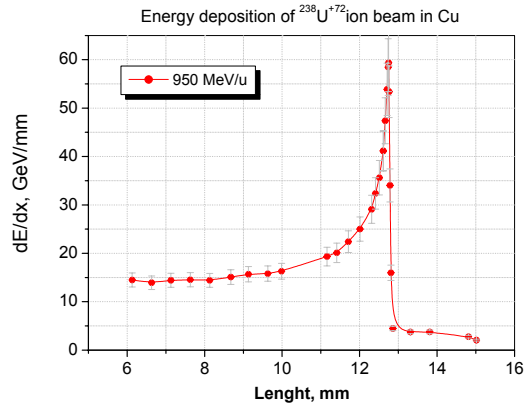

Figure 5: Energy deposition of $^{238}U^{+72}$ ion beam with 950 MeV/u energy in Cu

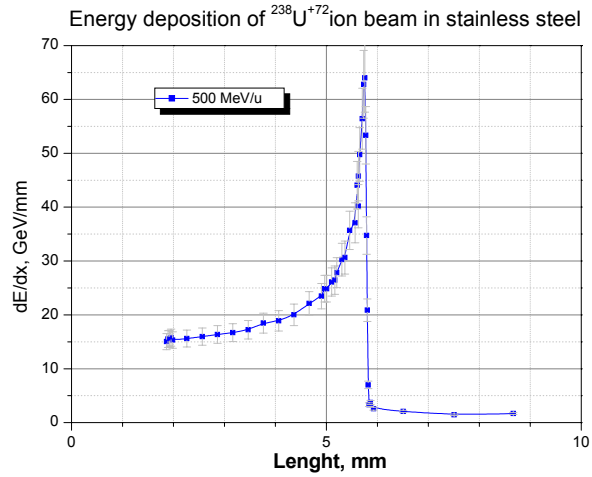

Figure 6: Energy deposition of $^{238}U^{+72}$ ion beam with 500 MeV/u energy in stainless steel

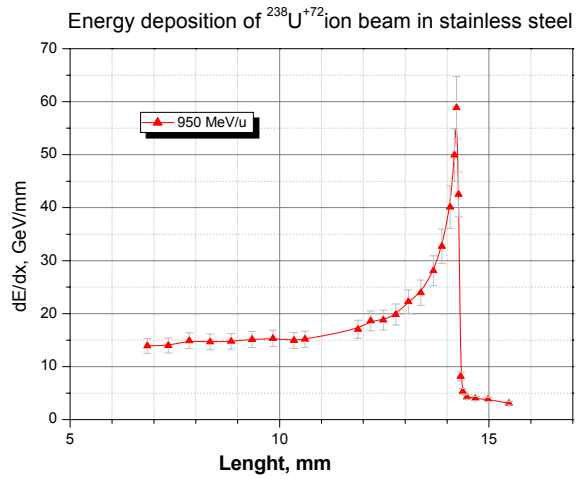

Figure 7: Energy deposition of $^{238}U^{+72}$ ion beam with 950 MeV/u energy in stainless steel

We demonstrate here the discrepancy of calculations with the measurement (and with each other) on the example of the 950 MeV/u U ions in Cu target. The resulting dE/dx curves are presented in Fig. 8.

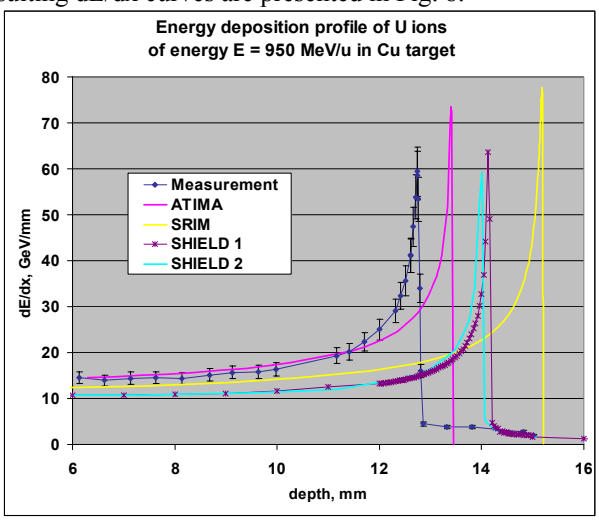

Figure 8: Comparison of the measured and calculated energy deposition profiles dE/dx for the case of 950 MeV/u U ions in Cu target.

The curve denoted as "SHIELD 1" in Fig.8 corresponds to the dE/dx in a cylindrical Cu target. The curve denoted "SHIELD 2" corresponds to more detailed modeling of the experimental set-up, which takes into account the Ti foil with thickness 30 μm and Al foil of thickness 100 μm situated in the ion-transportation channel in front of the target as well as the real geometry of the set-up itself, consisting of a) the Al foil of the primary calorimeter (for the beam energy calibration) with thickness 250 μm, b) the two wedges made of Cu of variable thickness, c) the cover of the main calorimeter with thickness of 100 μm and d) the measuring Al foil of the main calorimeter with thickness of 150 μm.

Note that SRIM and ATIMA calculate the stopping power without taking into account nuclear reactions (besides the elastic recoils in case of SRIM).

The SHIELD code takes into account the nuclear reactions although the modeling of the electronic stopping power for the ions and fragments are not taken into account in great details like in ATIMA and SRIM. The SHIELD calculations showed that although about half of the U beam would be fragmented by the end of the penetration depth the main contribution to the dE/dx was nevertheless given by the original U projectiles. This justifies a good agreement of the measured dE/dx with the detailed calculation of the stopping power for the U ions by the ATIMA code.

The measured range of the 950 MeV/u U ions in Cu is presented in Table 1 together with the results of calculation by the codes. The difference between the measured range values and calculated by the ATIMA code is almost within the accuracy of the measurement (which is about 4%).

Table 1: Measured and calculated range of U ion with energy E=500 and 950 MeV/u in iron and Cu targets

Measurement & Codes	**Range, mm**			
	Fe, 500	**Cu, 500**	**Fe, 950**	**Cu, 950**
Measurement	5.9±0.2	5.3±0.2	14.3±0.4	12.8±0.4
ATIMA	6.1	5.4	14.7	13.4
SRIM	6.5	5.9	16.1	15.2
SHIELD	5.9	5.4	15.1	14.1

The deviation of the measured values with the calculated is the largest for the SRIM output. The difference with the SHIELD code may be explained by the simplicity of the dE/dx modeling of the stopping power by the SHIELD code: it uses the basic Bethe formula, which is sufficient in modeling the energy deposition in bulk materials. The height of the measured dE/dx curve at the Bragg peak coincides with the ATIMA and SHIELD calculation within the accuracy of the method (about 7-10 %).

We would like to note here that not all the results are processed yet and more dE/dx measurements are planned at GSI for May 2005.

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