MEASURED RESIDUAL ACTIVITY INDUCED BY U IONS WITH ENERGY 500 MEV/U IN CU TARGET *

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Abstract

Several laboratories in the world have started or plan to build new powerful ion accelerators. These facilities promise to provide very valuable tools for experiments in fundamental nuclear physics, physics of high energy density in matter and for medical applications as well. One of the most important problems that have to be solved during the design stage is the radiation protection of the accelerator. Due to the complexity, it is hardly possible to obtain reliable radionuclide production data for accelerator structure materials from radiation transport codes. Thus, experimental data measured at presently existing facilities are necessary for the evaluation of the induced levels of radioactivity around intense heavy ion accelerators. The uranium beam losses are most dangerous in the FAIR facility. Results of the measurement of activity induced by U beam with energy of E = 500 MeV/u in the copper target are presented in this paper.

INTRODUCTION

Uranium beams with intensity up to 10^{12} ions are planned for the FAIR facility [1]. Beam losses at a level of about 5% of full beam intensity are expected during the slow extraction from the SIS100 synchrotron.

Measurements of the residual radioactivity induced by U ions of different energies in Cu and stainless steel targets have been taken at GSI Darmstadt. In this paper we present the results of measured residual radioactivity induced by U ions with energy 500 MeV/u in a Cu target and discuss possible “hands-on” maintenance problems in the tunnel of the SIS100 synchrotron of FAIR.

EXPERIMENTAL SETUP

The experimental setup is presented in Fig.1. The targets were installed and fixed on a special support. Two lasers, fixed on the walls of Cave A, were used for alignment of the target with the beam axis. The transverse target size for all samples was 50 mm. The beam diameter in each experiment was not larger than 11 mm. The thickness of the target was chosen according to the ion energy: it was twice the range of U ions. Thus the beam is completely stopped in the target. The target was assembled from plates of different thickness with 0.5 mm thick activation foils inserted in-between the disks, as shown in Fig. 2.

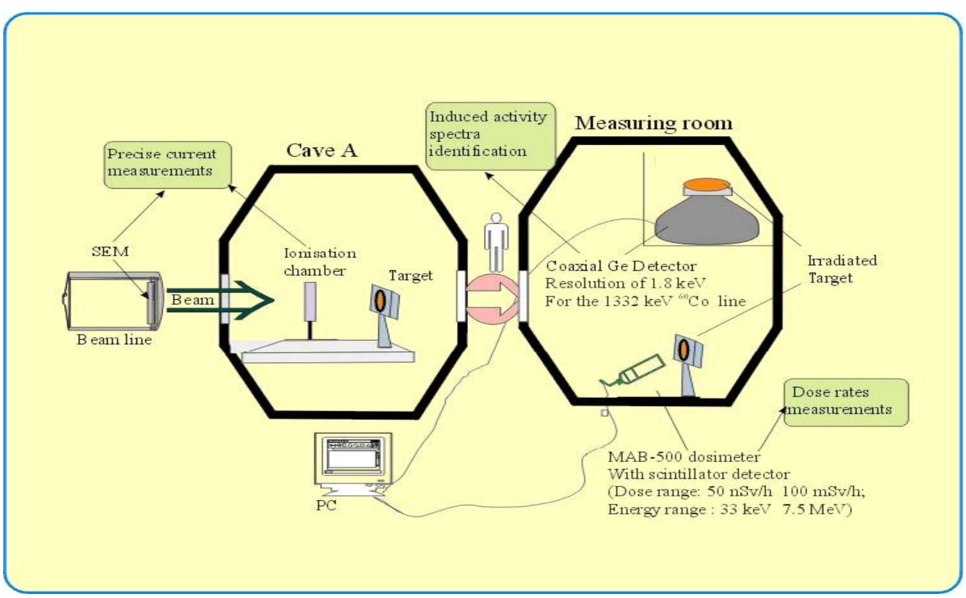

Figure 1: Experimental setup for the induced radioactivity measurements.

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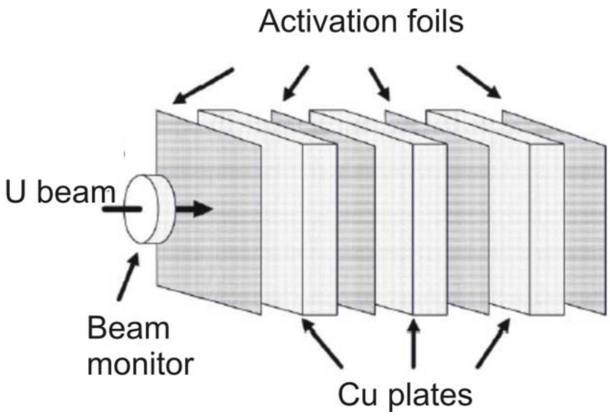

Figure 2: Target configuration

RESULTS OF THE MEASUREMENT

Dose-rate Decay

The target was irradiated continuously by a pulsed beam for about 20 h. The short-lived isotopes with decay times of about 10 h and less have already reached saturation during this long irradiation time. Thus one may deduce from the decay curve of the whole target activity the effective decay time constants for short-lived isotopes. In Fig. 3, the fit of the decay curve with two exponential components is presented.

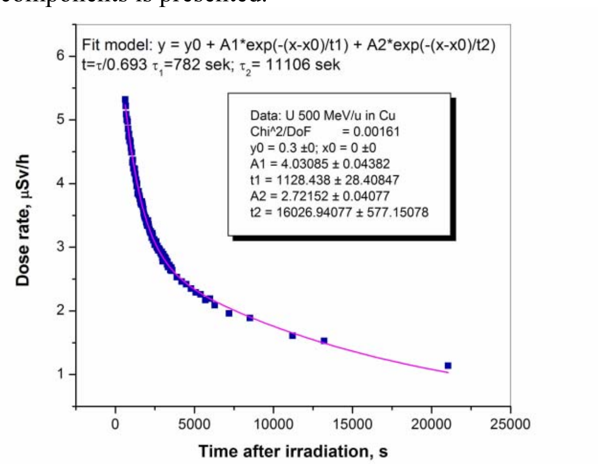

Figure 3: Decay curve for Cu target with 11 mm thickness irradiated by a ^{238}U beam with energy of 500 MeV/u for 20 h (total dose 4.66*10^{11} ions).

Detected Isotopes

The activation foils were analyzed by gamma-ray spectroscopy. The following isotopes were detected in the activation foils:

a) the isotopes produced by fragmentation of the target nuclei: ^{7}Be, ^{22,24}Na, ^{28}Mg, ^{42,43}K, ^{44,44M,46,47,48}Sc, ^{48}V, ^{48,51}Cr, ^{52,54}Mn, ^{52,59}Fe, ^{55,56,57,58,60}Co, ^{57}Ni, ^{62,65}Zn

b) the isotopes produced by fragmentation of the projectile nuclei (i.e. ^{238}U) and their lifetimes: ^{99}Mo - 65.94 h , ^{103}Ru - 39.26 d, ^{126}I - 13.11 d , ^{126}Sb - 12.46 d, ^{127}Xe - 36.4 d, ^{131}I - 8.02 d, ^{131}Ba – 11.5 d, ^{140}Ba – 12.75 d, ^{237}U – 6.75 d.

c) the daughter product of produced isotopes: ^{140}La (daughter product of ^{140}Ba)

Depth Profile of the Activity

Measurement of the activity of different isotopes created in the activation foils gives the distribution of the activity as a function of depth. As an example, results of the gamma-spectra measurement of the residual activity of Co isotopes with good abundance in the activation foils in comparison with the simulations with the help of the FLUKA [2] and the SHIELD [3] codes are shown in Figs.4-6. For FLUKA calculations the last but one version of the code was used. The new version, released recently, handles residual activation better. Calculations with the new version are under way currently and will be published later, but we do not expect significant changes in calculated production rates for Co isotopes produced by fragmentation of the target nuclei.

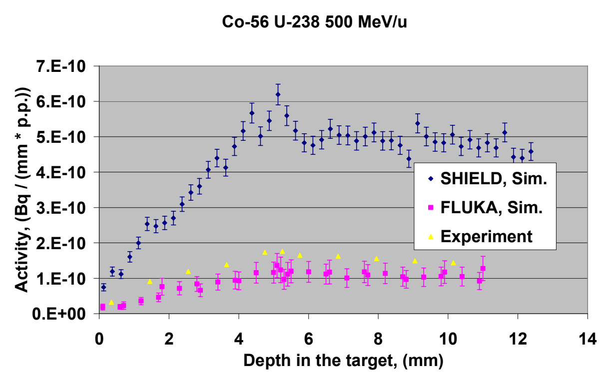

Figure 4: Activity of ^{56}Co: yellow – measured, lilac – FLUKA, blue – SHIELD.

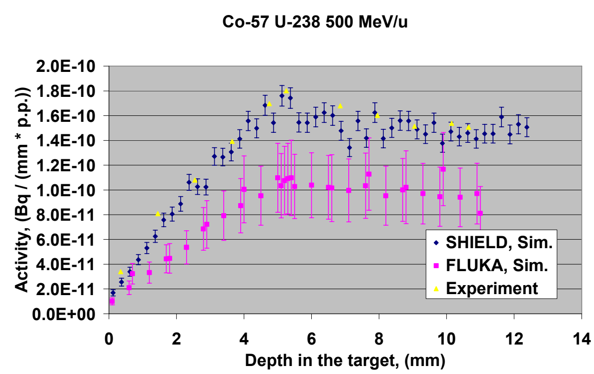

Figure 5: Activity of ^{57}Co: yellow – measured, lilac – FLUKA, blue – SHIELD.

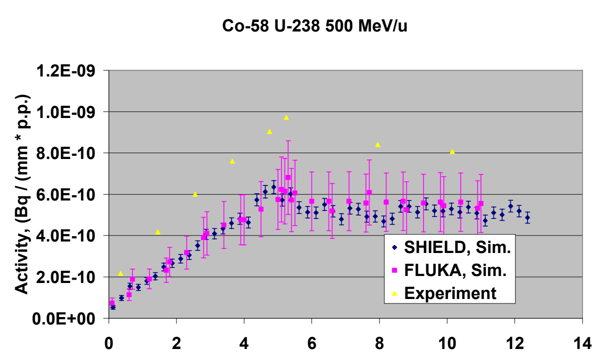

Figure 6: Activity of ^{58}Co: yellow – measured, lilac – FLUKA, blue – SHIELD

Comparison with simulations for all isotopes detected in the activation foils shows that the depth profile behavior is satisfactorily described by both codes and the numeric discrepancy between the measured and calculated activities as well as the discrepancy between the codes themselves are overall within a factor of 5.

Estimates of the Residual Activity in SIS100

The knowledge of the residual activity of individual isotopes allows us to estimate the danger of the residual radioactivity for the "hands-on" maintenance in the accelerator.

In order to get estimates of the residual activity in the tunnel of SIS100 synchrotron of FAIR, we consider the slow extraction regime. In this regime, the planned beam loss level is about 5% of total intensity of 10^{12} U ions in a cycle with duration of 1.7 s. We also assume that the lost beam particles are distributed uniformly along the beam pipe over 30 m distance downstream the electrostatic extraction septum.

In Fig.7, evolution of the residual activity in SIS100 in one year is presented for three machine runs: each one is three months long, with one month break for maintenance between the runs.

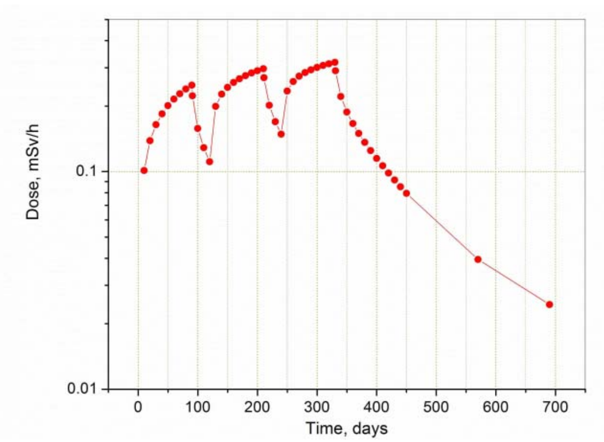

Figure 7: Calculated increase and decay of the accumulated dose rate in the vicinity of the slow extraction point of SIS100 synchrotron of FAIR.

One may notice the increase of the dose-rate due to the accumulation of isotopes with long lifetime. One month break between the runs is not sufficient to "cool" the accumulated residual activity down to the starting level so the activity builds-up more and more with each run.

According to the German Radiation Protection Ordinance, there are three levels of access to the areas with high dose-rate level:

- From 0.5 μSv/h to 3 μSv/h is the survey area – free access
- Above 3 μSv/h is the radiation controlled area – it is basically the radiation level in the experimental caves of GSI
- Above 3 mSv/h – inaccessible areas – access is absolutely forbidden

One may conclude from Fig.7 that the dose-rate in the vicinity of the extraction point of SIS100 is above 3 μSv/h but below 3 mSv/h. This means that the access to the machine is allowed under strict control with a special access procedure worked out by the radiation protection group in accordance with the ALARA (As Low As Reasonably Achievable) principle.

One should note that the estimates are done for U ions with energy E = 500 MeV/u, whereas the extracted beam from SIS100 will have energy of E = 1 GeV/u. The measurements of the residual activity induced by U ions of E = 950 MeV/u have recently been performed at GSI (in April-June 2006). The results of the measurements are being processed currently and will be reported later. At the moment we can say that the residual activity induced by lost U ions of energy E = 1 GeV/u should be more than factor of 2 higher compared to the E = 500 MeV/u case.

CONCLUSION

Measurements of the residual activity induced by U ions of different energies in Cu and stainless targets were performed at GSI Darmstadt. Residual activities of long-lived isotopes determined from the measurements allowed to estimate the danger of the residual activity for the "hands-on" maintenance in SIS100 synchrotron of FAIR. The estimates have shown that the dose-rate level is below the access limit of 3 mSv/h.

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