MEASUREMENT OF ACTIVATION INDUCED BY AN ARGON BEAM IN A COPPER TARGET AT THE SIS18*

E. Mustafin, G. Fehrenbacher, R. Hasse, I. Hofmann, D. Schardt, K. Weyrich,
GSI, Darmstadt, Germany
A. Fertman#, A. Golubev, M. Prokuronov, B. Sharkov, ITEP, Moscow, Russia

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, the experimental data which can be measured at the presently existing facilities (SIS-18, Ganil) are necessary for the evaluation of the induced levels of radioactivity around intense heavy ion accelerators. Results of the measurement of activation induced by Argon beam with energies of E = 300, 500, 800 MeV/u in the copper target are presented in this paper.

MOTIVATION

In recent years, requirements from new technological and research applications for particle accelerators have emerged, giving rise to new radiation shielding aspects and problems. For the new high-power accelerators currently being designed, activation of the accelerator structure has become an important issue. The main emphasis of new heavy ion accelerator projects (SIS-100, TWAC or future HIDIF) focuses on the technical developments needed to increase the achievable beam intensities by up to two orders of magnitude. The activation, however, produced by accelerators of such high power, has not yet been quantified. Hence, novel safety aspects evolving from the increased radioactive inventory of such facilities will obviously play the major role in the design and approval procedure. The experimental investigation of potential radiation risks during normal heavy ion accelerator operation is proposed in a new GSI-INTAS project. Three main topics that have to be investigated in this direction are as follows:

1. Characterization of radiation from selected components of the beam line, especially from the extraction section: production rates of radioactive nuclides
2. Long time prediction of radioactive inventory around the beam transport system
3. Characterization of the hazard from secondary neutrons for intense heavy ion beam facilities

The project deals with the first and second topic. The data for primary ion fluxes and final doses on the target close to the real irradiation conditions at the different sections of SIS – 100 facility will be measured. Based on these data the radioactive inventory around the crucial points at the beam line and the environmental impact released by accelerators will be predicted for long-time periods. An understanding of the production of radionuclides can help reduce personnel exposures through the selection of more appropriate machine component materials and the optimisation of decay ("cool-down") times recommended after the beam has been turned off.

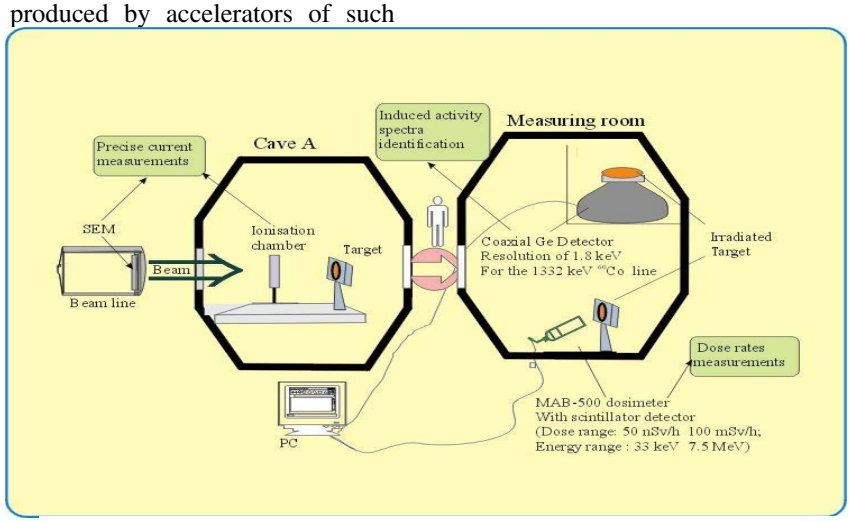

Figure 1: Experimental setup for the induced radioactivity measurements

*Partialy supported by the grant of GSI-INTAS Project #03-54-3588
#Alexander.Fertman@itep.ru

DESCRIPTION OF EXPERIMENT

The SIS-18 beam-time for the investigation of the residual radioactivity of copper after the argon beam irradiation was carried out in 2003. This work was the continuation of the ion induced radioactivity experimental program, which was started at GSI in 2002, from the copper and stainless steel irradiation by carbon beams [1]. The experimental setup is presented on Fig. 1. Cylindrical 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 target diameter for all samples was 50 mm. The beam diameter in each experiment was not larger then 11 mm. The thickness of the target was chosen according to each ion energy. It was two times larger than the range of Argon ions (see the table 1). Thus the beam is completely stopped in the target. The targets were not a solid cylinder but assembled from disks of different thickness with 1 mm thick foils inserted between the disks.

Table 1: The target parameters and irradiation conditions

Target configuration Cu - set of disks mm:	Energy (MeV/u) / range (mm)[1]	Target thickness	Total flux (ions)
1,7, 1, 7, 1, 5, 1, 1, 1, 5, 1, 5, 1, 5, 1, 3, 1	498.69/ 23.6	47 mm	$4.79*10^{11}$
1, 7, 1, 7, 1, 7, 1, 7, 1, 7, 1, 5, 1, 1, 1, 7, 1, 7, 1, 7, 1, 5, 1, 5, 1, 5, 1, 5, 1	798.96/ 47.74	97 mm	$1.19*10^{11}$
1, 3, 1, 3, 1, 1, 1, 1, 3, 1, 5, 1	298.39/ 10.64	22 mm	$3*10^{11}$

[1]- calculated by SRIM code [2]

During the irradiation experiment, a transmission-type ionisation chamber and a secondary-electron transmission monitor (SEETRAM) were used to measure the Argon beam intensity and total flux almost without influencing the beam quality [3]. The calibration of the SEETRAM current with respect to the primary beam intensities were performed by counting the particles with a scintillator proportional counter. So, the number of 500 MeV/u ions propagating through the SEETRAM detector is: $N = Q_{SEM}(pC)*0.970*10^6$. For other energies the calibration coefficients were recalculated under the assumption that secondary-electron emission induced by a heavy-ion beam passing through a thin titanium foil is proportional to the stopping power of matter for concrete ion energy [3]. Irradiations were performed with 300 MeV/u , 500 MeV/u and 800 MeV/u ^{40}Ar ion beams delivered from SIS-18. The average fluxes of the Argon ions were $2*10^7$ - 10^8 ions per pulse depending on the ion energy. The beam extracted from the synchrotron has a time structure with a pulse width of 1 s at time intervals every 2.9 – 3.8 s depending on the beam energy. We chose copper targets in the irradiation experiments as typical material of an accelerator structure. The parameters of the targets and irradiation conditions are summarized in table 1.

For Ar energy 300 MeV/u and total equivalent dose rate decay curve was measured with a MAB-500 dosimeter with a scintillator detector (dose range: 50 nSv/h -- 100 mSv/h; gamma energy range: 33 keV -- 7.5 MeV). The results of the measurements are shown in Fig. 2. Based on these data the mean values of the "half-life" of the short-lived isotopes that determine the dose rates a short time after irradiation were estimated for copper target: $\tau = 859 \pm 92$ s. Here it has to be mentioned than the allowed limit for personnel is 20 mSv/year or 1 mSv/h at extreme conditions.

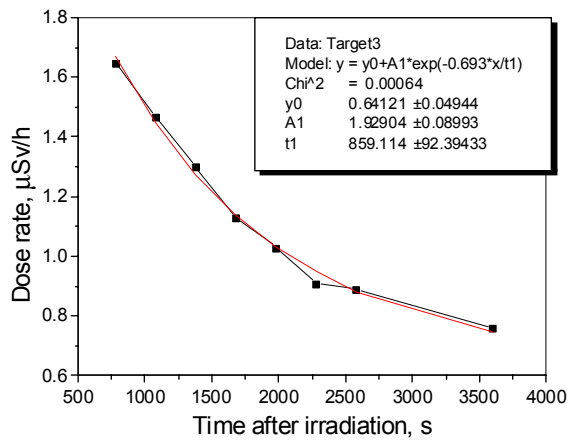

Figure 2: Decay curve for copper target 22 mm thickness irradiated by argon beam $E_0 = 300$ MeV/u during 3 h 22 min ($3*10^{11}$ ions). Distance between the target and detector - 30 cm.

MEASUREMENTS OF SPECTRA

After the end of irradiation, the targets were transported to the special lead box for cooling. The γ-spectrometric measurements started about 24 hours after the of irradiation. Precise gamma-spectrometry measurements for element identification were performed using a Canberra HpGe – GEM-45195-S-SV detector by coupling with the 4096 multi-channel analyzer. The detector is powered by a Selena HV supply and interfaced to a Canberra spectroscopy amplifier. Data acquisition is processed with the software package WINGAM running on a PC. The amplification was chosen for the registration of γ-quanta with energies between some tens of keV and about 2 MeV. Typical resolutions ranged from about 1 keV at 122 keV of ^{57}Co to about 1.8 keV at 1332 keV of ^{60}Co. The energy and efficiency of the spectrometer was preliminarily calibrated at two different distances of 5 and 15 cm between the detector and gamma source. These distances were used in the following measurements of the spectra. By virtue of the small irradiated area (~ 11 mm) this geometry allows to treat the target as a point-like

source. A total of seven calibrated standard sources were used to characterize the detector system: ^{22}Na, ^{60}Co, ^{133}Ba, ^{137}Cs, ^{152}Eu, ^{226}Ra, ^{241}Am.

RESULTS

In total, around 75 spectra were measured during one month after the end of the irradiation. For the identification of the elements we used not only the energy position [4] of the gamma peak, but also the experimentally measured decay curve parameters. Table 2 gives the residual nuclides measured in the activation targets. In comparison with the carbon irradiation experiment [1] the list of residual nuclides is shorter and consists of 27 isotopes. Short-lived nuclides ^{41}Ar, ^{44}Sc, ^{56}Mn and ^{61}Co were not registered in the argon-irradiated samples, because the cooling time was increased.

Table 2: Residual nuclides measured in the copper target

PROJECTILE –TARGET	RESIDUAL NUCLIDES IN ACTIVATION TARGET
^{40}Ar – Cu (nat)	^{7}Be, ^{22,24}Na, ^{28}Mg, ^{42,43}K, ^{44M,46,47,48}Sc, ^{48}V, ^{48,51}Cr, ^{52,54}Mn, ^{52,59}Fe, ^{55,56,57,58,60}Co, ^{57}Ni, ^{61}Cu, ^{62,65}Zn, ^{67}Ga

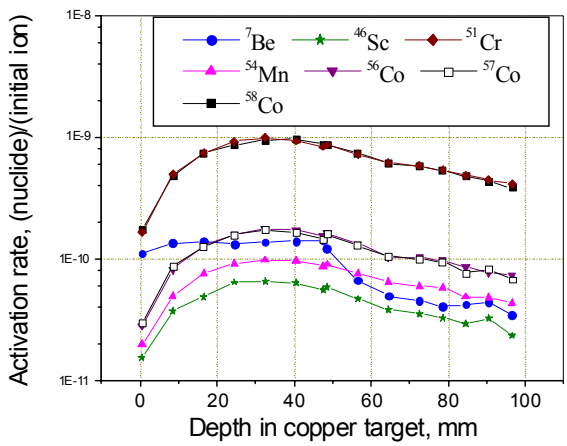

Figure 3: Spatial distribution of activation rates of different nuclides in the copper target after ^{40}Ar E_0= 800MeV/u irradiation

Thus, from the irradiation experiments we identified the residual nuclei in these activation foils and obtained the spatial distribution of their activation rates in the copper targets along the ion range. Fig. 3 shows the spatial distributions of different nuclei in the copper target for 800 MeV/u ^{40}Ar ion bombardments. This figure indicates that the spatial distributions of the activation rates of Co isotopes, which are close to those of the target consisting of natural Cu (^{63}Cu and ^{65}Cu), increase with depth in the copper target, while the spatial distribution of ^{7}Be, which has a much smaller mass than natural Cu has a constant distribution in the copper target up to the depth of the energy range of the incident beam. The spatial distribution of ^{46}Sc exhibits an intermediate profile between those two. The character of the spatial distribution curves is similar to the results obtained by E. Kim et al. at HIMAC [5]. Furthermore the experimental results show that many radionuclides are produced in the target where the depth is beyond the energy range of the incident beam (47.74 mm). This production is initiated due to a large amount of secondary neutrons, protons and light fragments.

Spectra measurements were carried out not only for activation foils but also for thick targets as a whole. Partial inputs of different nuclides to the dose rate around the targets, irradiated by an Argon beam were experimentally determined. Based on these data the induced radioactivity levels during and after the continuous irradiation of the accelerator constructions can be predicted. In Fig. 4 prognoses of the dose rate 10 cm away from the total stopping range copper target 10 days continually irradiated by 300 MeV/u Argon beam 10^{11} p/s. One can see that about 170 days after the end of irradiation the dose rate near the target is still higher than the allowed limit for personnel at extreme conditions.

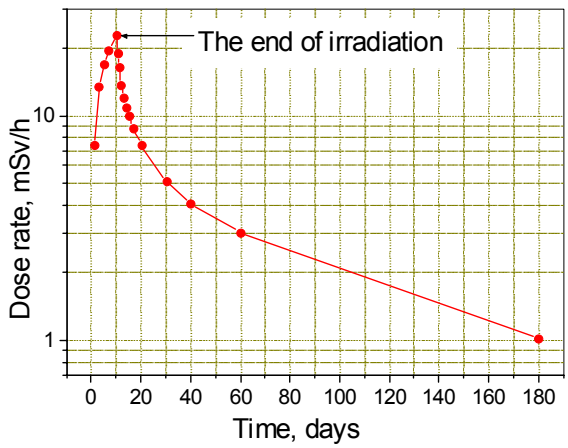

Figure 4: Predictions of the induced radioactivity around Copper target continually irradiated by 300 MeV/u Argon beam

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