# SOME PROBLEMS OF RESIDUAL ACTIVITY MEASUREMENTS

***P. Katrík[1,2,3], E. Mustafin[1], I. Strašík[1], M. Pavlovič[3]***

*[1] GSI Helmholtzzentrum für Schwerionenforschung Darmstadt, Planckstrasse 1, 64291 Darmstadt, Germany,*

*[2]Technische Universität Darmstadt Karolinenplatz 5, 64289 Darmstadt, Germany,*

*[3]Slovak University of Technology, Faculty of Electrical Engineering and Information Technology, Ilkovičova 3, 812 19 Bratislava, Slovakia*

*E-mail: P.Katrik@gsi.de*

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## 1. Abstract

As a preparatory work for constructing the Facility for Antiproton and Ion Research (FAIR) at GSI Darmstadt, samples of copper were irradiated by 500 MeV/u $^{238}$U ion beam and investigated by gamma-ray spectroscopy. The nuclides that contribute dominantly to the residual activity have been identified and their contributions have been quantified by two different methods: from the whole-target gamma spectra and by integration of depth-profiles of residual activity of individual nuclides. Results obtained by these two methods are compared and discussed in this paper.

## 2. Introduction

Activation of accelerator components due to beam-losses is an important issue for high-power accelerators, because the residual activity induced by lost particles is one of the main access-restrictions for "hands-on" maintenance. That is why our studies have been focused on experimental determination of residual activity in some construction materials [1-3]. In this paper, we report results for copper irradiated by 500 MeV/u $^{238}$U ion beam. The irradiated samples were analyzed by gamma-ray spectroscopy in two different modes: (1) whole-target measurements and (2) depth-profiling. Comparison of these two methods is presented and discussed.

## 3. Experiment and methods

In order to allow for depth-profiling of residual activity, the target was assembled from 34 individual foils 50 mm in diameter and two different thicknesses (0.5 mm and 0.1 mm). The overall target thickness was 10.7 mm. The copper with purity better than 99.9% and density of 8.96 g/cm$^3$ and 8.92 g/cm$^3$ was used for the 0.5 mm and the 0.1 mm thick foils, respectively. The thinner foils were placed in the region of expected range of primary beam that was estimated by SRIM, ATIMA and dE/dx experiment [4].

The beam was extracted from SIS-18 with a repetition rate of 0.285 Hz and spill duration of 1 s. The beam intensity was monitored by a secondary electron transmission monitor. Irradiation time was 20 h and the total number of ions delivered to the target was $4.66\times10^{11}$. After irradiation, the samples were analyzed by gamma-ray spectroscopy. The spectra were measured 34 h, 16 days and 56 days after the end of irradiation in the whole-target mode. Depth-profiles from individual target foils were measured 2-6 and 62-68 days after the end of irradiation. All activities were re-calculated backwards to the time-point at the end of irradiation. The gamma-ray spectroscopy chain is described in [1]. It was based on

the Canberra HPGe GEM-45195-S-SV detector allowing for detecting gamma-photons up to 2 MeV.

## 4. Results and discussion

Results for all identified nuclides can be found in [1]. However, this data is based on the whole-target method only. We completed the analysis by depth-profiling of the residual activity and calculated the total activity of each nuclide by integration of its depth-profile. After that, we compared activities obtained from the whole-target measurement and depth-profiling. In some cases, a good agreement was observed, in other cases, the deviation up to 81% was found. Tab. 1. contains results for selected nuclides.

The whole-target measurements are fast, but the signal is affected by self-absorption in the target. If the sample is placed directly on a detector, the activity measured by the detector, $A_D$, is given as:

$$A_D = \int_0^L A_L(x) e^{-\mu x} dx \qquad (1)$$

where $A_L$ is the activity per unit length, $\mu$ is the linear attenuation coefficient and $L$ is the target thickness. The problem is that the $A_L(x)$ function cannot be obtained from the whole-target measurements. It can only be approximated under some assumptions. In our case, a uniform depth-distribution of the activity was assumed [1].

The above mentioned problem can be resolved by depth-profiling of residual activity. The depth-profiles are obtained by measurements of individual foils and the total activity is calculated by integration of the depth-profile. Fig. 1 shows measured depth-profiles of selected nuclides. The following knowledge can be gained from the depth-profiles:

- real shape of the $A_L(x)$ function;
- the target-activation products can be clearly distinguished from the projectile fragments;
- interference of several nuclides can be recognized from the profile shape.

Tab. 1. *Activities of selected nuclides obtained by whole-target measurement and depth-profiling.*

| Isotope | Energy [keV] | $A_1$ (16 days) [Bq/mm/ion] | $A_2$ (56 days) [Bq/mm/ion] | $A_{12}$ [Bq/mm/ion] | $A_3$ (2-6 days) [Bq/mm/ion] | $\delta A_{12}/A_3$ [%] |
|---|---|---|---|---|---|---|
| 7Be | 477.595 | 1.63E-10 | 1.67E-10 | 1.65E-10 | 2.982E-10 | 44.66 |
| 44mSc | 271.13 | 1.01E-09 | below MDA | 1.01E-09 | 1.098E-09 | 8.01 |
| 51Cr | 320.0824 | 7.42E-10 | 7.3E-10 | 7.36E-10 | 1.175E-09 | 37.36 |
| 52Mn | 935.538 | 1.22E-09 | below MDA | 1.22E-09 | 1.147E-09 | 6.37 |
| 58Co | 810.775 | 7.3E-10 | 7.04E-10 | 7.17E-10 | 7.526E-10 | 4.73 |
| 103Ru | 497.080 | | 1.26E-10 | 1.26E-10 | 1.648E-10 | 23.55 |
| 131I | 364.489 | 2.51E-10 | below MDA | 2.51E-10 | 2.661E-10 | 5.69 |
| 131Ba | 216.078 | 1.06E-10 | 1.03E-10 | 1.045E-10 | 5.567E-10 | 81.23 |
| 140Ba | 537.261 | 1.37E-10 | 1.42E-10 | 1.395E-10 | 3.849E-10 | 63.75 |

$A_1$, $A_2$ and $A_3$ – activities measured 16, 56 and 2-6 days after the end of irradiation; $A_{12}$ – average value of $A_1$ and $A_2$; $\delta A_{12}/A_3$ – the relative difference between the $A_{12}$ and $A_3$; MDA = minimum detectable activity.

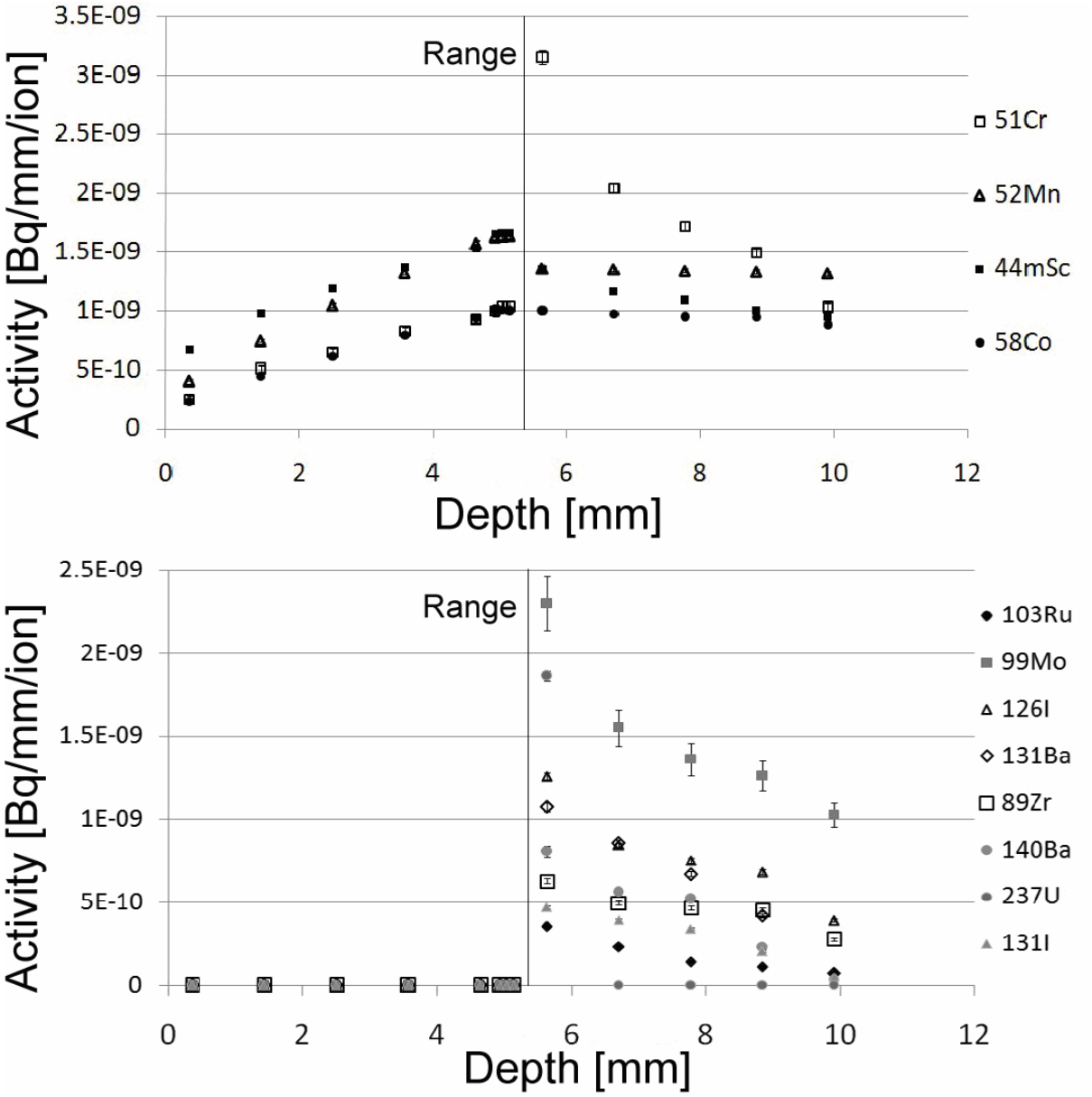


Fig.1: *Typical residual activity depth-profiles of target activation products (left panel) and projectile fragments (right panel). Target: copper irradiated by 500 MeV/u $^{238}U$ beam, irradiation time 20 h, $4.66\times10^{11}$ ions.*

## 5. Comparison of the results

As it can be seen in Tab. 1., the difference between the two methods varies between few percent up to 81%. In 12 out of 32 nuclides, the difference was less than 10%. Good agreement is achieved for target activation products (their profiles are relatively flat) without interference with short-lived nuclides. Differences greater than 10% have two causes: (1) the presence of a short-lived nuclide and/or (2) insufficient depth-resolution of the depth-profiling. The presence of the short-lived nuclides is evident from the profile (it distorts its shape by a local peak, e.g. $^{51}Cr$). This means that the measurement must be repeated later. In case of projectile fragments, the depth-resolution must be optimized in order to increase numerical integration accuracy. However, this is of less concern, because the contribution of the projectile fragments to the overall target activity is negligible [1, 2].

## 6. Conclusion

The activity obtained by depth-profiling is more accurate, because of taking into account the real shape of the $A_L(x)$ function. More-over, depth-profiling provides additional information about the activation mechanism (target activation, projectile fragments) and the presence or absence of interfering nuclides.


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