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Evaluation of an ADS lead target activation: Comparison of computations and measurements

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Abstract

The measurements and calculations have aimed at the verification of codes and data bases applied in modeling of transmutations in the spallation target and the resulting radioactivity. In experiments cylindrical Pb targets were exposed to the beam of 660 MeV protons. Using γ-spectrometry, a number of radionuclides were identified in Pb and Bi samples irradiated in the targets. Axial and radial distributions of several nuclides production rates were determined. Three types of the distribution shapes were distinguished: Bi isotopes, medium and heavier nuclides. The distributions of Bi isotopes reveal a sharp characteristic peak about 30 cm inside the target. The comparison of experimental results with calculations (MCNPX, FLUKA and LAHET) shows agreement within one order of magnitude, at the worst. Almost always the C/E ratio is between 3 and 1/3. However, no single code and/or reaction model yields good results for all examined nuclides.

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Keywords: Nuclear transmutations; Radioactivity; Spallation target; 660 MeV proton beam

1. Introduction

The designing of an accelerator driven system (ADS) needs numerous precise neutron transport calculations. The applied codes and data base should be verified experimentally. The presented experiments were thought as a part of such verification, especially for transmutations in construction materials and the resulting radioactivity. They were conducted on the 660 MeV proton beam at the Dzhelepov Laboratory of Nuclear Problems in JINR Dubna (Russia).

2. Experiments and results

The proton beam intensity was monitored by an ionization chamber calibrated with the $^{12}C(p,pn)^{11}C$ reaction and with Al foil and the $^{27}Al(p,3n3p)^{22}Na$ and $^{27}Al(p,x)^{7}Be$ reactions. The beam distribution on the target front surface was also monitored. In the first experiment, the axial distributions of radionuclides activity were measured in the Pb target. The target consisted of several pieces of 4.5 and 0.5 cm thick cylindrical parts and of 31 pieces of 1 mm thick lead samples, all 80 mm in diameter (Fig. 1).

The values of parameters applied in the experiment were: max. proton yield $I_{p,max} = 3 \times 10^{10}$ p/s, irradiation time $t_i = 9$ h, min. decay time $t_{d,min} = 10$ h, total number of protons $N_p = (26.3 \pm 1.9) \times 10^{13}$. The samples and monitors after irradiation were counted in typical vertical counting geometry with the use of HPGe coaxial detector of known efficiency characteristics for point γ-sources. The characteristics were also computed using the MCNP code [1]. For the large Pb disc samples ($\Phi 80 \times 1$ mm) the counting efficiency was computed using the MCNP and LAHET [2] codes. The absolute activity of a given

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radionuclide was calculated from the measured γ spectra. For some nuclides axial distributions of activity inside the Pb target were obtained. Examples of the results are presented in Fig. 2.

For comparison with the measurements, calculations simulating the experiment were done with the use of MCNPX code, versions 2.5b and 2.5d [3] and different model options. As an example, the nuclides: ^{83}Rb (fission), ^{185}Os (spallation) and ^{207}Bi (p,xn), representing different types of reactions, were selected for presentation of the comparison results (Figs. 3 and 4). For other measured nuclides the comparisons have been presented in earlier reports from our investigations [4] and used in the diploma thesis at the University of Karlsruhe [5] for ADS validation work (^{205}Bi and ^{206}Bi).

Fig. 1. Structure of the lead target: (diameter—80 mm, length—308 mm). Sample thickness—1 mm.

From the practical point of view also evaluation of the homogenised activity of whole target can be of interest, especially for the liquid metal targets. Such evaluation has been done on the basis of both the experiment and calculations (MCNPX and FLUKA [6]). The comparison is presented in Table 1.

Separate experiment was devoted to the assessment of radial distributions of radioactivity induced in Bi samples irradiated in the Pb target. In this case, the spallation target consisted of 6 Pb cylinders 5 cm thick and 16 cm in diameter (Fig. 5). Between the first 4 cylinders: the sample holders made of lead were introduced.

Based on 4 series of γ-spectra measurements, after 2 h, 4 days, 1 month and 300 days decay time, activities

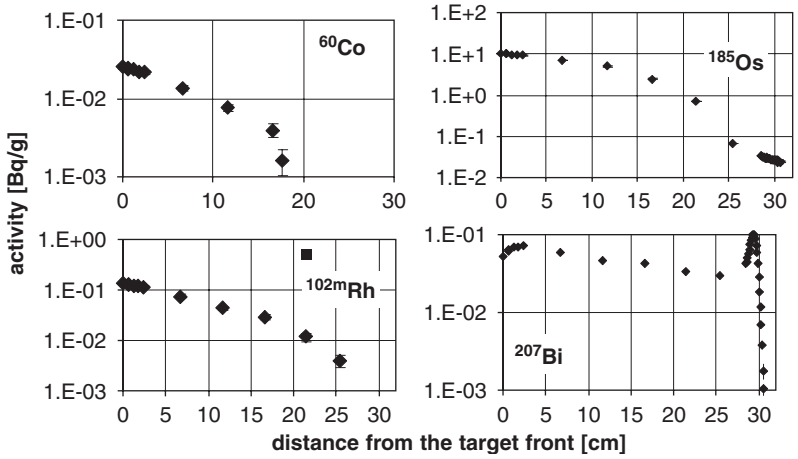

Fig. 2. Distributions of the specific activity of radionuclides along the Pb target irradiated with 660 MeV protons.

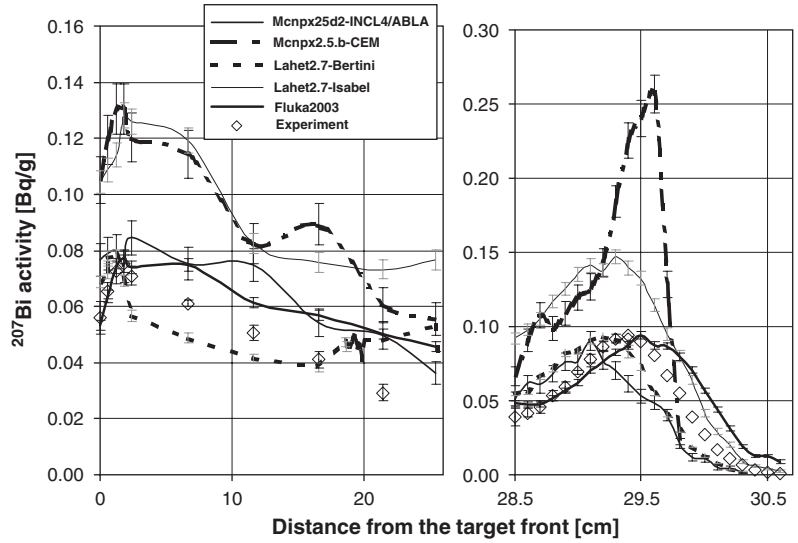

Fig. 3. Example (^{207}Bi) of measured and calculated production rate distribution of Bi radionuclides along the Pb target.