Available online at www.sciencedirect.com

ScienceDirect

Physics Procedia 90 (2017) 69 – 78

Physics Procedia

Conference on the Application of Accelerators in Research and Industry, CAARI 2016, 30 October – 4 November 2016, Ft. Worth, TX, USA

Determination of the Secondary Neutron Flux at the Massive Natural Uranium Spallation Target

M. Zeman[a,b]*, J. Adam[b,c], A.A. Baldin[b,d], W.I. Furman[b], S.A. Gustov[b], K. Katovsky[a], J. Khushvaktov[b], I.I. Mar`in[b], F. Novotny[a], A.A. Solnyshkin[b], P. Tichy[b,c,e], V.M. Tsoupko-Sitnikov[b], S. I. Tyutyunnikov[b], R. Vespalec[b,e], J. Vrzalova[b,c,e], V. Wagner[c,e], L. Zavorka[b,e]

[a] *Brno University of Technology, Brno 616 00, Czech Republic*
[b] *Joint Institute for Nuclear Research, Dubna 141 980, Russia Federation*
[c] *Nuclear Physics Institute of the ASCR, Rez near Prague 250 68 Czech Republic*
[d] *Institute for Advanced Studies "OMEGA", Dubna 141 980, Moscow region, Russian Federation*
[e] *Czech Technical University in Prague, Prague 166 36, Czech Republic*

Abstract

The flux of secondary neutrons generated in collisions of the 660 MeV proton beam with the massive natural uranium spallation target was investigated using a set of monoisotopic threshold activation detectors. Sandwiches made of thin high-purity Al, Co, Au, and Bi metal foils were installed in different positions across the whole spallation target. The gamma-ray activity of products of (n,xn) and other studied reactions was measured offline with germanium semiconductor detectors. Reaction yields of radionuclides with half-life exceeding 100 min and with effective neutron energy thresholds between 3.6 MeV and 186 MeV provided us with information about the spectrum of spallation neutrons in this energy region and beyond. The experimental neutron flux was determined using the measured reaction yields and cross-sections calculated with the TALYS 1.8 nuclear reaction program and INCL4-ABLA event generator of MCNP6. Neutron spectra in the region of activation sandwiches were also modeled with the radiation transport code MCNPX 2.7. Neutron flux based on excitation functions from TALYS provides a reasonable description of the neutron spectrum inside the spallation target and is in good agreement with Monte-Carlo predictions. The experimental flux that uses INCL4 cross-sections rather underestimates the modeled spectrum in the whole region of interest, but the agreement within few standard deviations was reached as well. The paper summarizes basic principles of the method for determining the spectrum of high-energy neutrons without employing the spectral adjustment routines and points out to the need for model improvements and precise cross-section measurements.

* Corresponding author.
E-mail address: Miroslav.Zeman@vutbr.cz

Peer-review under responsibility of the Scientific Committee of the Conference on the Application of Accelerators in Research and Industry
doi:10.1016/j.phpro.2017.09.021

Peer-review under responsibility of the Scientific Committee of the Conference on the Application of Accelerators in Research and Industry

Keywords: ADS; spallation target; neutron flux; threshold activation detectors

1. Introduction

The Accelerator Driven Systems (ADS) is one of the ways to transmute spent nuclear fuel (SNF) from nuclear power plants and high level radioactive material, originally planned to be used for military purposes. Such a system consists of the external particle source, accelerator, spallation target made of a heavy metal, and a blanket consisting of SNF or other nuclear material. The principle of ADS has been described in details, e.g. (Grand et al. 1985) and (Bowman et al. 1992). Projects focused on ADS research are realized around the world. For example, in Europe the MYRRHA project is being built, see more details elsewhere (Abderrahim et al. 2010). The project will be based on nuclear reactor with ability to operate in both subcritical and critical modes driven by a proton accelerator. Other projects are planned around the world, for example TEF in Japan - (Sasa 2015) and C-ADS in China (Huang et al. 2015).

An important parameter for transmuting SNF and high-level radioactive material is the neutron spectrum of a spallation source. Both the spectrum and intensity of the secondary neutron field vary with the position inside the target. The detection of the secondary neutron field in spallation targets can be done with helium detectors, track detectors, or threshold activation detectors. Recently, several activation experiments were performed at the Joint Institute for Nuclear Research (JINR) within the international collaboration E&T-RAW, see e.g. (Zavorka et al. 2015), (Khushvaktov et al. 2016) and (Adam et al. 2015).

This paper provides a description of two such experiments carried out with the spallation target made of natural uranium. In these experiments, monoisotopic threshold activation detectors in the form of sandwiches were used for characterization of neutron field generated in the spallation target. The target was irradiated with a 660 MeV proton beam. The detectors were placed inside of the spallation target in different positions. The main focus of the measurement were the (n,xn) reactions leading to the production of radioisotopes with $T_{1/2}$ higher than 100 minutes in the interval of the threshold energies from 3 MeV up to 186 MeV. The energy spectrum of secondary neutron field was determined across the whole volume of the spallation target.

2. Experimental methods

The experiments were carried out at JINR, at the Dzhelepov Laboratory of Nuclear Problems. The *QUINTA* target was composed of five natural uranium cylinders. The cylinders were 36 mm in diameter and 104 mm in length. Uranium cylinders were clad in 1 mm thick aluminum. The cylinders were fixed in hexagonal aluminum sections with wall thickness of 5 mm. Sections were separated by 17 mm wide air gaps. The first section had a beam window, 80 mm in diameter, four other sections had no windows. The total weight of the target was 540 kg, where the mass of metallic uranium was 512 kg. *QUINTA* is shown in Figure 1. The set-up was surrounded by the 100 mm thick lead shielding.

2.1. Target irradiation

The irradiation was performed using a synchrocyclotron particle accelerator, called Phasotron. The Phasotron accelerates protons up to 660 MeV. The protons impinge into the *QUINTA* target and generate the secondary neutron field. Two experiments were performed using high purity monoisotopic sandwiches. The samples positions are shown in Figure 1 *b).* All samples were fixed on the aluminum plates. The samples of ^{27}Al, ^{59}Co and ^{197}Au were packed like a sandwich. The ^{209}Bi samples were fixed on the right side of the sandwiches at aluminum plates. Figure 2 represents the sandwich of samples with bismuth. The masses of the samples were about 1.3 g for aluminum, 6 g for the bismuth samples, 5.5 g for the cobalt samples and 1g for the gold samples. In the first experiment five activation sandwiches