Applied Radiation and Isotopes 107 (2016) 225–233

Contents lists available at ScienceDirect

Applied Radiation and Isotopes

journal homepage: www.elsevier.com/locate/apradiso

Study of secondary neutron interactions with ^{232}Th, ^{129}I, and ^{127}I nuclei with the uranium assembly “QUINTA” at 2, 4, and 8 GeV deuteron beams of the JINR Nuclotron accelerator

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HIGHLIGHTS

- The natural uranium assembly, "QUINTA", was irradiated with 2, 4, and 8 GeV deuterons. The ^{232}Th, ^{127}I, and ^{129}I samples have been exposed to secondary neutrons produced in the assembly at a 20-cm radial distance from the deuteron beam axis.
- The spectra of gamma rays emitted by the activated ^{232}Th, ^{127}I, and ^{129}I samples have been analyzed and several tens of product nuclei have been identified.
- For each of those products, neutron-induced reaction rates have been determined.
- The transmutation power for the ^{129}I samples is estimated.
- Experimental results were compared to those calculated with well-known stochastic and deterministic codes.

ARTICLE INFO

Article history:
Received 10 February 2015
Received in revised form
30 June 2015
Accepted 2 November 2015
Available online 4 November 2015

Keywords:
Transmutation
Fission reactions
Accelerator driven system

ABSTRACT

The natural uranium assembly, “QUINTA”, was irradiated with 2, 4, and 8 GeV deuterons. The ^{232}Th, ^{127}I, and ^{129}I samples have been exposed to secondary neutrons produced in the assembly at a 20-cm radial distance from the deuteron beam axis. The spectra of gamma rays emitted by the activated ^{232}Th, ^{127}I, and ^{129}I samples have been analyzed and several tens of product nuclei have been identified. For each of those products, neutron-induced reaction rates have been determined. The transmutation power for the ^{129}I samples is estimated. Experimental results were compared to those calculated with well-known stochastic and deterministic codes.

1. Introduction

The ADS-related research has long been attracting attention of the international scientific community primarily due to societal concerns with the problem of the long-lived radioactive waste storage (Bowman et al., 1992; Janssen, 2004) and the proposals of subcritical nuclear power plant concepts based on the uranium–thorium cycle, and controlled by high-energy particle accelerators (Accelerator Driven System(s)) (Rubbia et al., 1994; Thorium Fuel Cycle, 2005). Such research has been actively conducted throughout the world for the last two decades at PNF (Poahng) (Kim et al., 2002), n-ToF (CERN) (http://pceet075.cern.ch/), MYRRHA (Belgium) (http://www.sckcen.be/myrrha/) and «Energy+Transmutation» setup at JINR (Dubna) (Krivopustov et al., 2009; Adam et al., 2005, 2007, 2008). The following programs are currently under development: SINQ (PSI) (http://sinq.web.psi.ch/), KEK (Japan) (http://www.kek.jp/intra-e/index.html), MYRRHA (Belgium), n-ToF (CERN), including other research programs at LANL (USA) (http://lansce.lanl.gov/indexC.html). The programs are focused on precise measurement of nuclear data and development of new materials in order to create prototypes of industrial ADS-systems.

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http://dx.doi.org/10.1016/j.apradiso.2015.11.002
0969-8043/

During the past several years, such studies have been conducted with accelerated particle beams at Nuclotron of VBLHEP (Veksler and Baldin Laboratory of High Energy Physics) JINR (Dubna) in the frameworks of the international collaboration Energy plus Transmutation of Radioactive Waste. This program has carried out a large number of experiments with the subcritical uranium target "QUINTA" (Коллаборация, 2012; Asquith et al., 2014; Furman et al., 2012; Zavorka et al., 2012; Suchopar et al., 2012), as well as the lead-graphite target "GAMMA-3" (Adam et al., 2011; Asquith et al., 2015). Several experiments were conducted using a solid lead target "GENERATOR" (Majerle et al., 2008; Adam et al., 2002; Henzl et al., 2002) at the proton beam of JINR DLNP (Dzhelepov Laboratory of Nuclear Problems) Phasotron.

In this paper we present new experimental data and a comparison with the calculations performed in the last two years in the course of studies of ^{232}Th, ^{129}I, and ^{127}I interactions with secondary neutrons using the "QUINTA" target assembly at the deuteron beams with energies 2, 4 and 8 GeV from the Nuclotron accelerator of the VBLHEP, JINR.

2. Structure of the setup "QUINTA"

Uranium assembly "QUINTA" is presented in Fig. 1. It consists of five sections of hexagonal shape (aluminum containers with an inscribed diameter of 284 mm). Containers are filled with cylindrical rods of natural uranium, having a sealed aluminum shell (external dimensions: 3.6 cm diameter, 10.4 cm in length, with a 1.72-kg weight of uranium). The containers are made of 6 mm thick aluminum. The first section, facing the deuteron beam contains 54 uranium rods and has a central beam window, 80 mm in diameter, installed in order to reduce its albedo and reduce the leakage of neutrons from the target. Four subsequent sections are structurally identical and contain 61 uranium rods. The mass of the natural uranium in each of these sections is $61 \times 1.72 = 104.92$ kg, and the total mass of uranium in the entire target is $298 \times 1.72 = 512.56$ kg. The filling factor of the 2nd, 3rd, 4th, and 5th uranium sections is about 0.8, and is ~0.6 of the entire assembly.

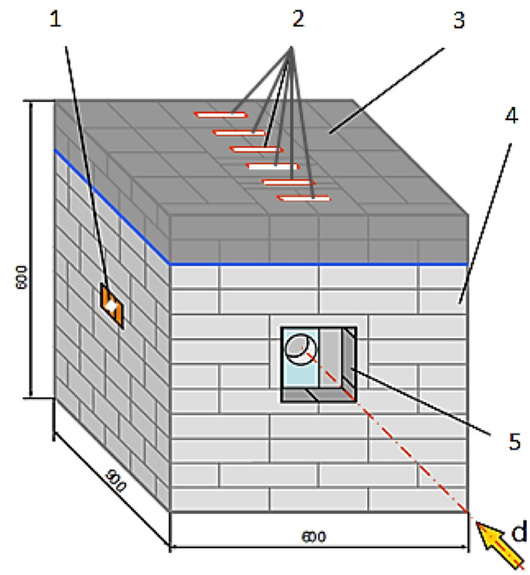

Fig. 2. The general view of the "QUINTA" setup, where 1 – window for placement of the transmutation samples, 2 – hatches for mounting and dismantling of detector probes and installation of the samples inside the uranium assemblies between Section, 3 – lead cover assembly, 4 – the lead assembly, 5 – the 15 × 15-cm^2 beam input window.

The uranium target is surrounded with a lead shielding of 10-cm thickness and a weight of 2545 kg with a beam entrance window of the dimensions of 15 × 15 cm^2 (see Fig. 2). There is a window of the 15 × 5-cm^2 size in the side lead shield wall near the third section, where the transmutation samples can be placed. The upper part of the lead assembly has a special hole for mounting and dismantling of detector samples as well as their installation inside the uranium assembly between sections.

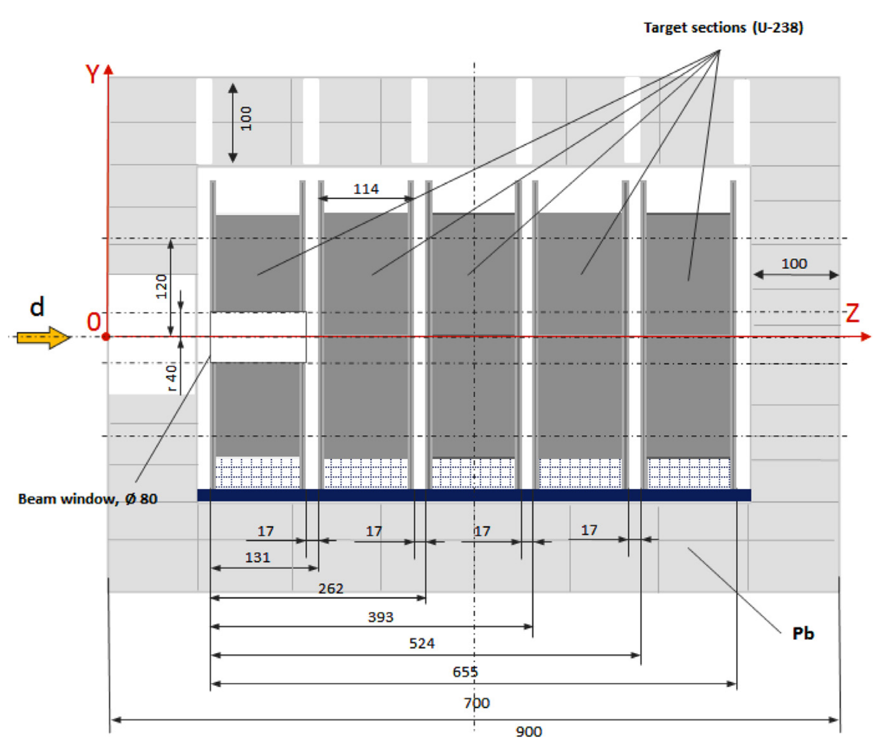

Fig. 1. The general scheme of the "QUINTA" setup.