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NEUTRON PHYSICS

Elemental Analysis of Engine Parts of the Proton Rocket Carrier with Resonance Neutrons

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Abstract—At the JINR Laboratory of Nuclear Physics, neutron–nucleus interactions are investigated for fundamental and applied purposes using the IREN pulsed neutron source. The applied research includes an elemental analysis of constituent materials of various devices. This paper describes the elemental-analysis techniques employed and reports the measurement of palladium abundances in the engine components of the Proton rocket carrier. The elemental-analysis technique involving resonance neutrons, currently implemented with the Romashka apparatus, is shown to be sensitive to palladium abundances at a level of 2 mg/g for samples with masses on the order of 60 g. Further developing the method will boost its sensitivity and allow for elemental analyses of larger samples and their assemblies.

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1. INTRODUCTION

The IREN pulsed source of resonance neutrons formed by an electron accelerator and a nonbreeding neutron-production target is operating at the JINR Laboratory of Nuclear Physics [1–3]. With a pulsed source, one can determine the incident-neutron energy by time-of-flight (TOF) towards measuring energy-dependent neutron–nucleus cross sections and related quantities. In particular, one can probe the elemental and isotope composition of a sample by characteristic neutron resonances [4]. Over the neutron energy range between fractions of eV and hundreds of keV, neutron–nucleon cross sections have pronounced resonant structures and the pattern of resonance positions, intensities, and underlying areas is individual for each isotope. Thereby, one is able to precisely discriminate different elements and their isotopes. The sensitivity of the method varies from element to element depending on the presence of signal and background resonances in the investigated region of neutron energy, on cross-section magnitudes in resonant regions, etc. Since neutrons have a high penetrating power, isotope discrimination by neutron resonances allows one to analyze quite massive samples with (as a rule) no preliminary processing.

In this paper, the above method is applied for measuring the palladium (Pb) abundance in the solder connecting some parts of a rocket engine. Palladium is one of the elements amenable to a resonance elemental analysis, since the neutron–Pd cross section features sufficiently strong resonances at neutron energies below 100 eV, where the sensitivity of the resonance technique is the highest. For this reason, even a small palladium abundance in a sample can be measured.

2. EXPERIMENTAL APPARATUS

The Romashka apparatus consists of 24 NaI(Tl) scintillation detectors of γ-quanta symmetrically configured around the neutron-beam axis [5]. The apparatus was installed in beam 4 of the IRENA neutron source over a time-of-flight baseline of 11.4 m. The neutron beam incident on the sample was formed with an upstream collimator of 10-cm-thick borated polyethylene (BPE). To keep the neutrons scattered on the sample from hitting the detectors, the sample was additionally shielded by a ring-shaped screen of 10-mm-thick boron carbide (B_4C) enriched to 94% of ^{10}B. The experimental arrangement is schematically shown in Fig. 1.

The detectors were read out with a 16-channel analog–digital converter (ADC) based on two PCI-standard plates, which can be plugged in and controlled by

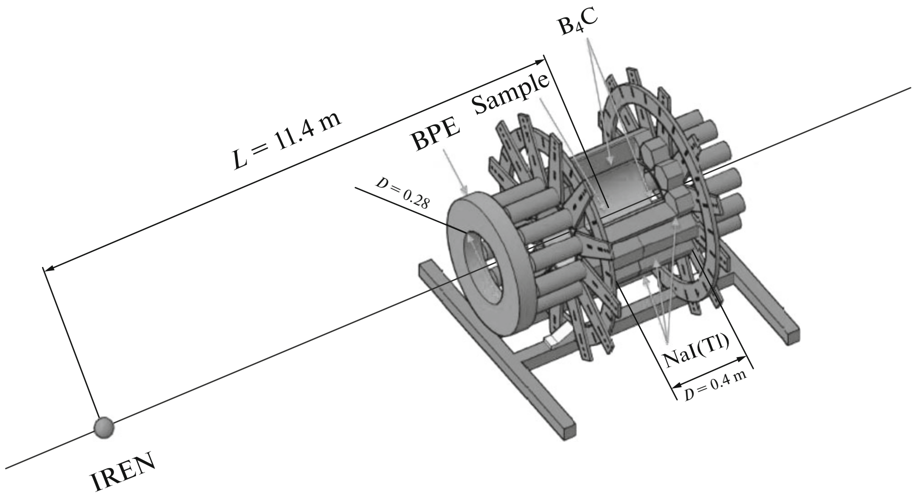

Fig. 1. Experimental arrangement and the Romashka apparatus.

a personal computer through a PCI-E bus for data exchange [6].

3. INVESTIGATED SAMPLES

We analyzed a 120-g rocket-engine component provided by the Roscosmos Corporation that was later sawn in two nearly equal parts (see Fig. 2). Of these, only one part with a mass of ~60 g contained Pd in its solder, as was earlier established by an X-ray fluorescence analysis carried out at the Institute of Physical and Technical Problems (Dubna). As a control sample for measuring the Pd abundance in the solder, we used a 5-g palladium foil with a natural isotope composition.

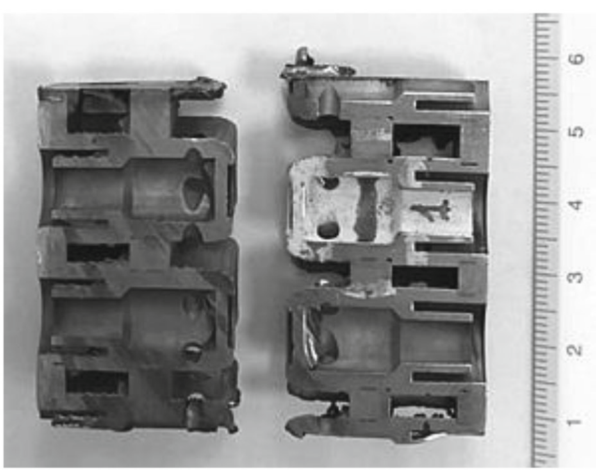

Fig. 2. Analyzed parts of a rocket engine. For the right-hand part, the location where palladium was found by an X-ray fluorescence analysis is marked as "1". The left-hand part is free of palladium.

4. ENERGY CALIBRATION OF TIME-OF-FLIGHT SPECTRA

Time-of-flight spectra were calibrated using 5 g of natural Pd as a control sample. The neutron time-of-flight spectra are shown in Fig. 3, where the resonance-neutron energies corresponding to peak positions are also quoted. In the process of radiative neutron capture by a nucleus, resonant values of neutron energy were determined as 11.79, 13.22, 25.15, 55.21, and 77.71 eV for the ^{105}Pd isotope and 33.10 and 90.81 eV for the ^{108}Pd isotope.

5. MEASUREMENTS WITH INVESTIGATED SAMPLES

The exposure time was 45 h for either investigated sample and 1 h for the control palladium sample. The mean neutron intensity and pulse duration amounted

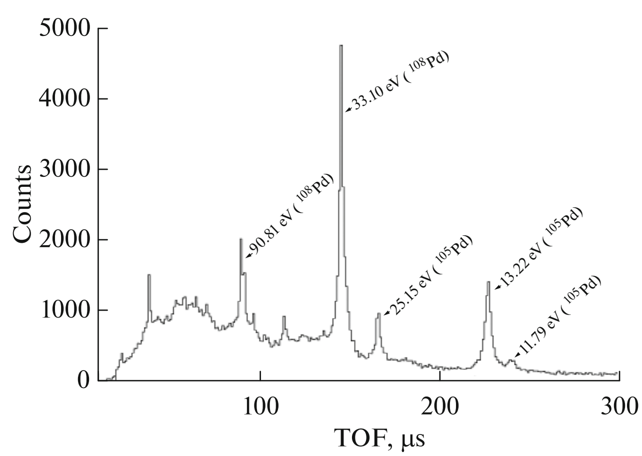

Fig. 3. Time-of-flight spectrum obtained for the Pd control sample.