Joint Institute for Nuclear Research
Frank Laboratory of Neutron Physics

Thermal neutron prompt gamma activation facility at IBR-2 reactor

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ABSTRACT

An experimental setup for determining the elemental composition of materials by Prompt Gamma-ray thermal Neutron Activation analysis (PGNAA) is under developing at Frank Laboratory of Neutron Physics (FLNP) 11b channel IBR-2 reactor of the Joint Institute for Nuclear Research (JINR) in Dubna, Russian Federation.

11b channel is equipped with mirror neutron guide which brings from reactor IBR-2 into experimental room thermal neutrons with the mean energy of ~ 0,025 eV. For registering the prompt gamma-rays from the interaction of the neutrons with sample nuclei we used high purity germanium gamma detector (HPGe) which has high energy resolutions and 80% relative efficiency of gamma-rays registration. The gamma-detector was protected with cadmium covered lead shielding.

A set of measurements was performed for determination of the hydrogen content in the nano diamond sample. Some preliminary results are reported.

INTRODUCTION

Prompt gamma-ray activation analysis is a measurement technique for nondestructive elemental analysis. Samples are irradiated by a beam of neutrons, in our case there are thermal neutrons with the mean energy 0,025 eV. In the moment of neutron capture by the nuclei there is emitting gamma radiation which is called "prompt". Each nuclei has characteristic set of gamma's energies [1]. When these gamma rays are measured using a high resolution germanium detector we can identify the nuclei by the energies of the gamma's and the intensities of this peaks can reveal the concentration of the needed element [2].

In the *Table 1* is shown the comparison of some characteristics between two types of techniques: induced (INAA) and prompt-gamma (PGNAA) neutron activation analysis:

Table. 1. Comparison between INAA and PGNAA [3]

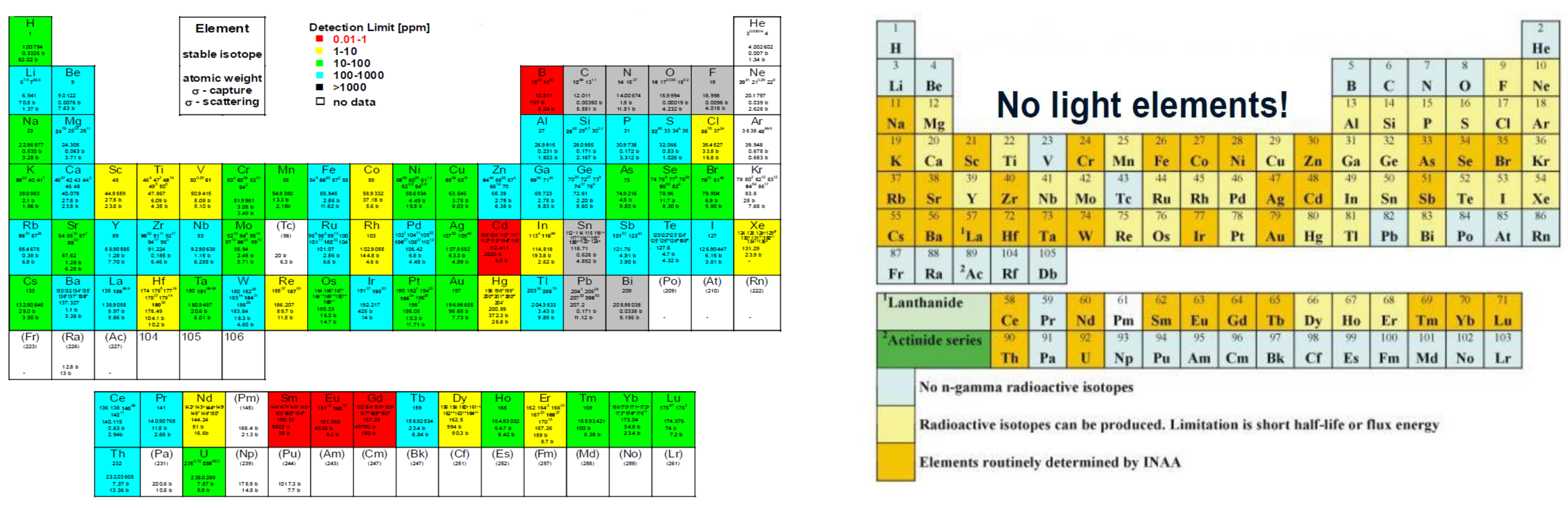
	INAA	PGNAA
Sample	10 mg	100 mg -1 g
Sample preparation	Drying, glass	None/ PTFE bag, vial
Irradiation	Reactor core	Guided beam of neutrons
Detection	Separated in time and space	On-line, during the irradiation
Spectrum	10-100 peaks, 3 MeV	100-5000 peaks, 12 MeV
Result turnover time	weeks	Few hours
Detection limits	ppm-ppb	>ppm, %
Cooling time	Several months	1-2 days

Prompt gamma activation analysis is a powerful method, but it is not yet well enough known in the nuclear data community. The method is suitable for analysis of major components of the sample. The elements with large cross sections can be determined at level below ppm. Non-destructive feature makes it an ideal tool for studying the archaeological samples, which helps archaeologists to find a lot of object's details and their history. It is unique in the observation of hydrogen indifferent on it's states. Is very sensitive for boron and trace element in the samples from places with volcanic activities [3].

There is two well known PGNAA setups in the world, one in National Institute of Standards and Technology, Gaithersburg, an second in Wigner Research Center for Physics, Budapest.

In the *Figure 1* is shown the sensibility of determining comparison between INAA and PGNAA for different elements of periodic table:

Figure. 1. Sensibility of determining for different element using PGNAA (left) and INAA (right) [3]

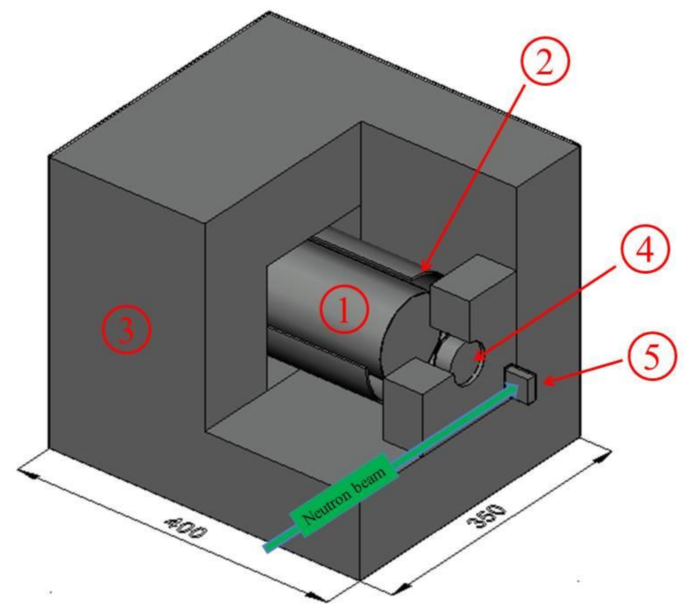


FACILITIES

The neutron source is pulsed reactor IBR-2 operating at a power of ~1.6 MW. The pulse frequency is 5 Hz and duration is about 300 µs. The mirror guide with length of 15 m and the radius of curvature 2000 m suppress the background generated by fast neutrons. The cross section of a neutron beam is ~ 5x2 cm^2 and neutron flux density at the guide's output is ~ $6 \cdot 10^5$ $n \cdot s^{-1}\, cm^{-2}$.

The HPGe radiation-resistant detector from Canberra with energy resolution 2.3 keV for the ^{60}Co 1332.5 keV and relative efficiency of 80% is placed 20 m long from the reactor core. The detector was set at a distance of 14 cm from the neutron beam axis and was surrounded by cadmium covered led shielding. The installation scheme is shown in *Figure 2*.

Figure. 2. Experimental setup scheme



1. HPGe gamma detector
2. Cd cover
3. Lead shielding covered with Cd
4. LiF window
5. Sample

EXPERIMENTAL DATA

The hydrogen content in the sample of nano diamonds was measured by using this new made setup for FLNP JINR. When neutrons are captured by protons gamma quanta with an energy of 2223.25 keV are promptly emitted. The capture cross section of thermal neutrons by protons is 0.334 b [4].

The number of detector's counts (peak absorption area) for a thin sample is:

$$N_\gamma(E_\gamma) = \Phi \cdot N_t \cdot \sigma_{n\gamma} \cdot \varepsilon(E_\gamma) \cdot t_{meas} \quad (1)$$

Φ - neutron flux density, N_t - number of the target nuclei, $\sigma_{n\gamma}$ - capture cross section, $\varepsilon(E_\gamma)$ - detector efficiency for a given energy, t_{meas}- measurement time.

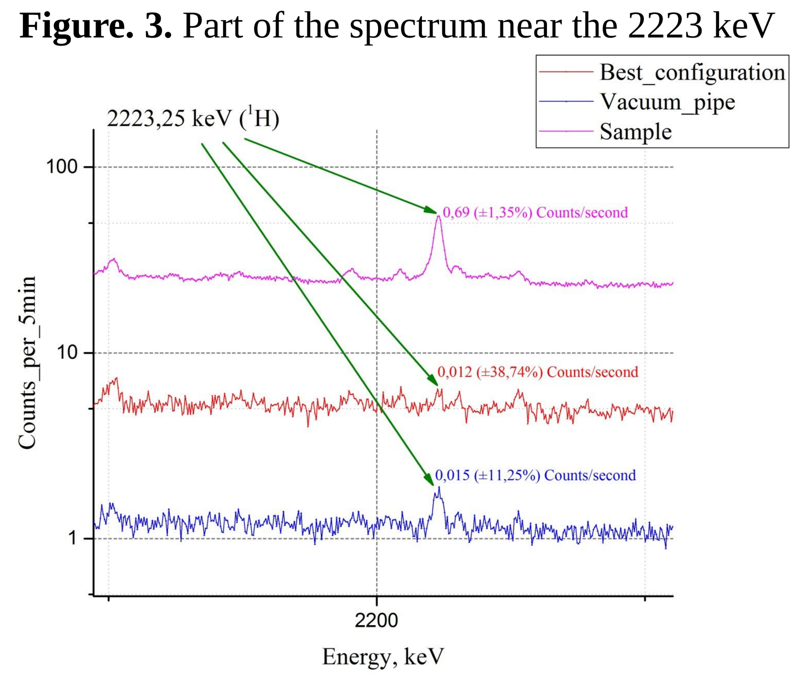
A polyethylene film with weight of 24 mg was used as a standard. Samples for irradiation was placed into the teflon bag with thickness 25 µm. The nano diamonds sample mass is 3.314 g. In *Figure 3* is shown a part of the spectrum near the 2223 keV line. All the acquired spectra were processed by the GENIE-2000 software.

Hydrogen mass containing in the nano diamonds sample was determined by the formula:

$$M_H = \frac{N_\gamma(Diam) - N_\gamma(bkgr)}{N_\gamma(PE) - N_\gamma(bkgr)} \cdot m_H(PE) \quad (2)$$

$N_\gamma(Diam)$, $N_\gamma(PE)$, $N_\gamma(bkgr)$ - counts per second for line 2223 keV in the measurements for nano diamonds, with PE film and without sample, $m_H(PE)$ - mass of hydrogen in polyethylene film.

Figure. 3. Part of the spectrum near the 2223 keV



In the *Table 2* is presented the results of nano diamond sample analysis:

Table 2. Preliminary results from analysis of nano diamond sample

	m, g	m(H), g	N_H	$S(2223)/t_{m,live}$
Background (Empty TeflonBag)	-	0	0	0.071 ± 0.005
Polyethylene (TeflonBag+PE)	0.024	0.0034	$2.05 \cdot 10^{21}$	0.336 ± 0.004
Nano diamands	3.314	**0.0088 ± 0.0003**	$5.3 \cdot 10^{21}$	0.753 ± 0.007

CONCLUSIONS

1. First attempt of building the PGNAA setup at FLNP IBR2 was successfully finished.
2. First results was obtained on the sample of hydrogen containing nano diamonds.
3. Background level was successfully compressed by using different techniques. Data analysis shows the sensibility level of the setup at 0.3 mg for hydrogen detection.
4. The FLNP's PGNAA setup can be modified to improve its sensibility.

LITERATURE

1. National Nuclear Data Center, Thermal Neutron Capture γ's (CapGam) (https://www.nndc.bnl.gov/capgam/)

2. Prompt Gamma-Ray Activation Analysis (PGAA) at National Institute of Standards and Technology (https://www.nist.gov/laboratories/tools-instruments/prompt-gamma-ray-activation-analysis-pgaa)

3. T. Belgya, Prompt gamma activation analysis at the Budapest Research Reactor, Physics Procedia 31, 2012, p. 99 – 109

4. T.S. Belanova et al., Radioactive Capture of Neutrons, handbook, M., Energoatomizdat, 1986 (in Russian)

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