THE FIRST TEST OF THE NEW NEUTRON GENERATOR AT THE VŠB - TECHNICAL UNIVERSITY OF OSTRAVA
PRVNÍ TEST NOVÉHO NEUTRONOVÉHO GENERÁTORU NA VŠB-TU OSTRAVA

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Abstract

The compact neutron generator MP320 (Thermo Scientific Inc.) operating on the principle of a deuterium-tritium reaction was tested before its planned application as the neutron source for the purpose of Fast Neutron Activation Analysis applications. Plates made from Al, Fe, Sn and Si were irradiated by a 14 MeV neutron beam and typical neutron induced reactions were identified.

Abstrakt

Kompaktní neutronový generátor MP320 (Thermo Scientific Inc.) pracující na principu deuterium-tritiové reakce byl testován před plánovaným využitím jako zdroj neutronů pro neutronovou aktivační analýzu pomocí rychlých neutronů. Destičky vyrobené z Al, Fe, Sn a Si byly ozářeny svazkem neutronů s energií 14 MeV a byly identifikovány reakce indukované neutrony typické pro uvedené prvky.

Key words: fast neutron activation analysis, neutron generators, material analysis

1 INTRODUCTION

The Fast Neutron Activation Analysis (FNAA) is a non-destructive method to identify about 60 natural elements [1-2]. When a sample is exposed to a 14 MeV neutron beam generated during a deuterium-tritium (D-T) fusion, (n,p), (n,2n), (n,α) and in some cases also (n,γ) or (n,n'γ) are the most important neutron reactions for the FNAA [1]. The formed nucleus is radioactive and decays emitting characteristic delayed gamma rays observed in the FNAA.

In this work, the D-T neutron generator (NG) MP320 (Thermo Scientific Inc.) [3] was tested by irradiating plates made from Al, Fe, Sn and Si and by identifying delayed γ-rays. The NG has a cylindrical shape (12 cm in diameter, 57 cm in length), and can produce 10^8 neutrons/s at maximum in continuous or pulsed regimes. The model MP320 of the D-T NG was selected for its relatively low cost, low power consumption (75 W), mobility (total weight of 12 kg) and its versatility: applications in the FNAA, the carbon detection via neutron induced prompt gamma emission and the investigation of biological effects of fast neutron irradiation.

2 EXPERIMENTAL PROCEDURE

During the experiment, the NG was operated in a pulsed mode with the frequency of 10 kHz, the duty factor D = 0.1 (10 %), the acceleration voltage U = 80 kV and the beam current I = 60 μA. The neutron yield was calculated from the known voltage U [kV], current I [μA] and the duty factor D according to the NG manual [4] from:

$$Y = 7060D\left(I - \frac{U}{20}\right)(U-40)^{3/2} \cong 10^7 \text{ n/s} \qquad (1)$$

The NG was located inside a 1 m thick aerated concrete (Ytong, a density of 650 kg m^{-3}) shielding in a 0.5 m x 0.75 m cavity (see Fig. 1).

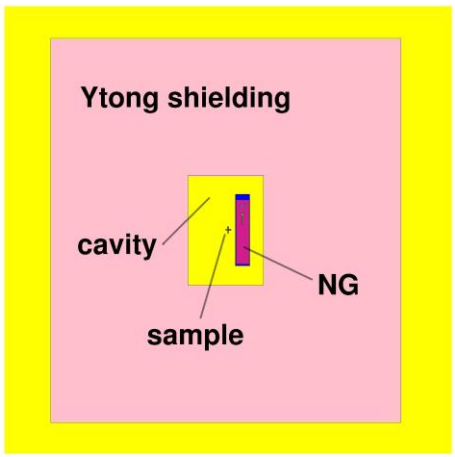

Fig. 1 A schematic drawing of the irradiation facility (NG, Ytong shielding and a sample position).

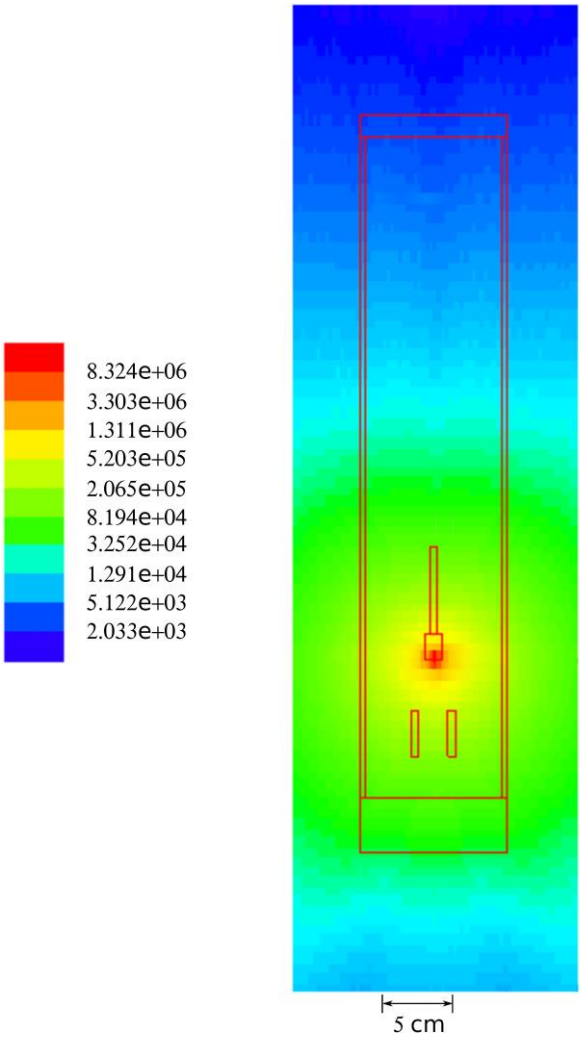

Fig. 2 Neutron flux distribution in cm^{-2} s^{-1} inside the NG and in its immediate vicinity.

Al, Fe, Sn and Si plates with a size of 11 × 3.8 cm and a thickness of 1 mm (masses: Fe – 32.93 g, Al – 11.77 g, Sn – 30.34 g, Si – 19.32 g) were irradiated by a neutron beam at a distance r = 10 cm from the NG target centre.

For a rough estimate of the neutron flux Φ through the irradiated sample surface, the isotropic neutron point source was considered and the following simple formula used

$$\Phi = \frac{Y}{4\pi r^2} \approx 8\times10^4 \text{ n cm}^{-2}\text{s}^{-1} \qquad (2)$$

The value is in agreement with the result of the MCNP5 (Monte Carlo Neutron-Particle Transport Code, Version 5) calculations of the neutron flux distribution based on the precised NG geometry and a material composition specification (see Fig. 2).

The HPGe GC3018 detector (Canberra Inc.) was utilized for the measurement of the neutron induced delayed γ-ray radioactivity. The detector was cooled in liquid nitrogen and positioned inside a massive shielding (Pb – 100 mm; Cu – 1 mm; Cd – 1 mm). The energy calibration was performed using standard ^{60}Co and ^{152}Eu point sources. The detector was connected through the Canberra DSA 1000 multichannel analyser (MCA) to the personal computer. To manage the detector and the MCA and to analyse γ-spectrometric data, the Genie 2000 spectroscopy software was selected.

The neutron beam irradiation of the samples proceeded twenty minutes. The samples were then placed close to the centre of the detector cap and γ-rays were recorded for eighty minutes. Tab. 1 presents neutron induced reactions identified in the measured spectrum (Fig. 3). Only the peaks corresponding to the produced radionuclides characterized by the appropriate half-lives were observed. In the gamma spectrum, the annihilation peak at 511 keV produced by the annihilation radiation in the surrounding material or the sample itself is clearly visible. The estimated sensitivity s of the experimental setup (minimum detectable mass) calculated from the known sample masses m, measured photopeak counts P and the background counts under the photopeak B [6],

$$s = \frac{m}{P} 3\sqrt{B} \qquad (3)$$

are shown in Tab. 1.

Tab. 1 The list of the neutron induced reactions clearly identified in the analyzed γ-spectrum.

Neutron induced reaction	Cross section (mb) [5]	Decay of radionuclide and its half life [5]	Gamma energy (keV)	Emission probability (%) [5]	Sensitivity (g)
^{27}Al(n,p)^{27}Mg	73	^{27}Mg (9.46 min) → ^{27}Al + e$^-$ + $\bar{\nu}_e$	843.8	71.80	0.38
^{27}Al(n,α)^{24}Na	123	^{24}Na (14.95 h) → ^{24}Mg + e$^-$ + $\bar{\nu}_e$	1014.5 1368.6 2754.0	28.20 99.99 99.86	0.79 1.3 0.86
^{56}Fe(n,p)^{56}Mn	114	^{56}Mn (2.58 h) → ^{56}Fe + e$^-$ + $\bar{\nu}_e$	846.8 1810.7 2113.1	100 27.20 14.40	0.33 1.2 2.6
^{28}Si(n,p)^{28}Al	280	^{28}Al (2.24 min) → ^{28}Si + e$^-$ + $\bar{\nu}_e$	1778.9	100	0.68
^{29}Si(n,p)^{29}Al	137	^{29}Al (6.6 min) → ^{29}Si + e$^-$ + $\bar{\nu}_e$	1273.4	100	1.6
^{124}Sn(n,2n)^{123}Sn	1515	^{123}Sn (40.1 min) → ^{123}Sb + e$^-$ + $\bar{\nu}_e$	160.3	85.70	1.4

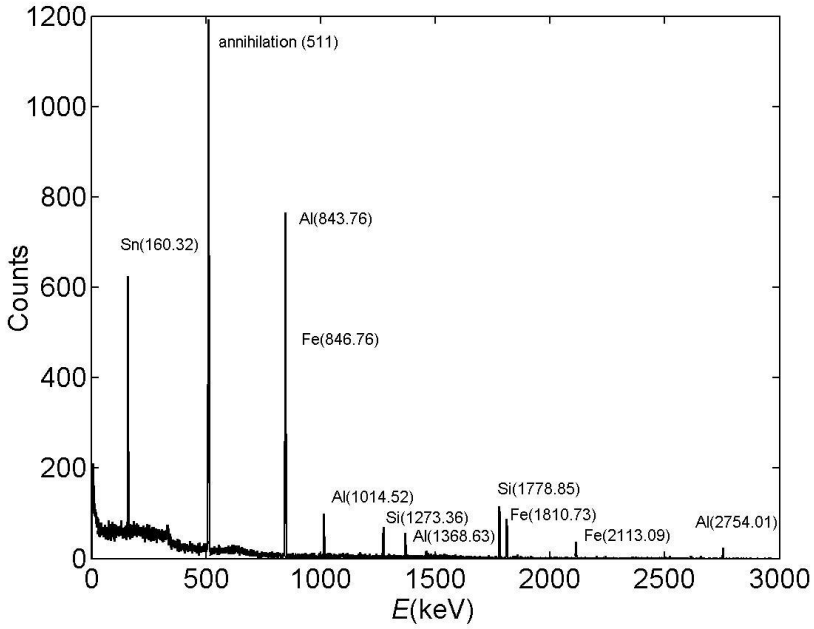

Fig. 3 Delayed γ-ray spectrum of the samples.

3 CONCLUSIONS

The aim of this work was to analyse the delayed γ-rays emitted by the neutron exposed metal plates, in order to test the NG D-T generator (MP320, Thermo Scientific Inc.). To confirm the optimal position of the plates at the closest distance from the housing of the NG, MCNP5, computations were performed. The achieved neutron flux activates Al, Fe, Sn and Si plates and the HPGe GC 3018 (Canberra Inc.) detector is efficient to record the delayed γ-rays emitted by the isotopes produced in the neutron induced reactions. The sensitivity of the experimental setup was found to be in a range of 0.3 - 2.6 g for the neutron yield 10^7 n/s. The highest sensitivities were observed for the gamma lines 846.8 keV (Fe – 0.33 g) and 843.8 (Al – 0.38 g). The maximum available neutron yield of the NG, 10^8 n/s, is expected to increase the sensitivity by a factor of 10.

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RESUMÉ

Pro studium struktury látky má neutron velmi užitečnou vlastnost – nulový elektrický náboj. Jaderné reakce vyvolané neutrony nejsou proto ovlivněny coulombovskou bariérou a mohou s větší či menší pravděpodobností probíhat ve velmi širokém intervalu energií neutronů. Během bombardování látky rychlými neutrony (14 MeV) zachytí některá jádra atomů neutron a proběhne jedna z jaderných reakcí (n,p), (n,2n), (n,α) a v některých případech i (n,γ) nebo (n,n'γ). Vzniklé jádro je většinou nestabilní a pokud není poločas rozpadu příliš malý, lze studovat zpožděné charakteristické γ-záření, které umožní určit izotop přítomný v ozařovaném vzorku i jeho množství (neutronová aktivační analýza rychlými neutrony). Množství izotopu ve vzorku je přímo úměrné intenzitě emitovaného γ-záření.

Za přispění Magistrátu města Ostravy byl zakoupen kompaktní neutronový generátor MP320 (Thermo Scientific Inc.), ve kterém dochází k fúzi deuteria a tritia a uvolňují se neutrony s energií 14 MeV. Maximální emisivita zdroje je 10^8 neutronů/s.

Předložená studie popisuje výsledky prvního testování neutronového generátoru v pulzním režimu s emisivitou 10^7 neutronů/s. Prezentován je seznam jaderných reakcí, které byly vyvolány bombardováním vzorků (Al, Fe, Sn, Si) neutrony, a příslušné energie emitovaného γ-záření změřené polovodičovým germaniovým detektorem. Hlavním výsledkem práce je úspěšné ověření funkčnosti generátoru a stanovení minimální detekovatelné hmotnosti pro studované prvky, která se pohybuje v rozmezí 0.3 – 2.6 g, přičemž nejlepších výsledků bylo dosaženo pro železo a hliník. Pro maximální emisivitu NG, 10^8 n/s, se očekává desetinásobné snížení minimální detekovatelné hmotnosti.