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Characterization of the graphite pile as a source of thermal neutrons

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HIGHLIGHTS

- We built a graphite pile as a source of thermal neutrons.
- We measure the thermal neutron fluence rate with different detectors.
- We model and verify the thermal neutron field homogeneity.

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ABSTRACT

A new graphite pile designed to serve as a standard source of thermal neutrons has been built at the Czech Metrology Institute. Actual dimensions of the pile are 1.95 m (W) × 1.95 m (L) × 2.0 m (H). At its center, there is a measurement channel whose dimensions are 0.4 m × 0.4 m × 1.25 m (depth). The channel is equipped with a calibration bench, which allows reproducible placement of the tested/calibrated device. At a distance of 80 cm from the channel axis, six holes are symmetrically located allowing the placement of radionuclide neutron sources of Pu–Be and/or Am–Be type.

Spatial distribution of thermal neutron fluence in the cavity was calculated in detail with the MCNP neutron transport code. Experimentally, it was measured with two active detectors: a small ^{3}He proportional detector by the French company LMT, type 0.5 NH 1/1 KF, and a silicon pixel detector Timepix with ^{10}B converter foil. The relative values of thermal neutron fluence rate obtained with active detectors were converted to absolute ones using thermal neutron fluence rates measured by means of gold foil activation. The quality of thermal neutron field was characterized by the cadmium ratio.

1. Introduction

For most materials, the absorption cross sections of low energy neutrons obey 1/v law. Consequently, most neutron measuring instruments comprise a detector of thermal neutrons located inside the polyethylene moderator to decrease the energy of neutrons before their detection. The development of such instruments requires testing and response calibration in the field of thermal neutrons. Availability of thermal neutron beams on nuclear reactors is limited and the access to them is rather complicated, therefore it is more convenient to moderate neutrons from the radionuclide neutron sources. Since radionuclide neutron sources produce neutrons with energies in the MeV range, it is necessary to use appropriate moderator material like heavy water or graphite to thermalize them and at the same time to avoid thermal neutron capture.

Thermal neutron fluence rate is commonly measured by means of gold activation detectors (Technical Report Series no. 107, 1970). The quality of moderated thermal neutron source spectra is characterized by the cadmium ratio R_{Cd} or cadmium coefficient F_{Cd}, see Eqs. (1) and (2).

$$R_{\mathrm{Cd}} = \frac{A_{tot}}{A_{epi}}, \tag{1}$$

$$F_{Cd} = \frac{R_{\mathrm{Cd}} - 1}{R_{\mathrm{Cd}}} = \frac{A_{tot} - A_{epi}}{A_{tot}}, \tag{2}$$

where A_{tot} is the activity of the irradiated bare gold foil and A_{epi} is the activity of the gold foil irradiated in a cadmium capsule, whose walls were 1 mm thick in this particular case. The effective energy cut-off E_{Cd} of the cadmium capsules used was 0.5 eV.

The parameters R_{Cd} and F_{Cd} are based on the properties of ^{113}Cd isotope (12.2% natural abundance) and ^{197}Au with unique neutron

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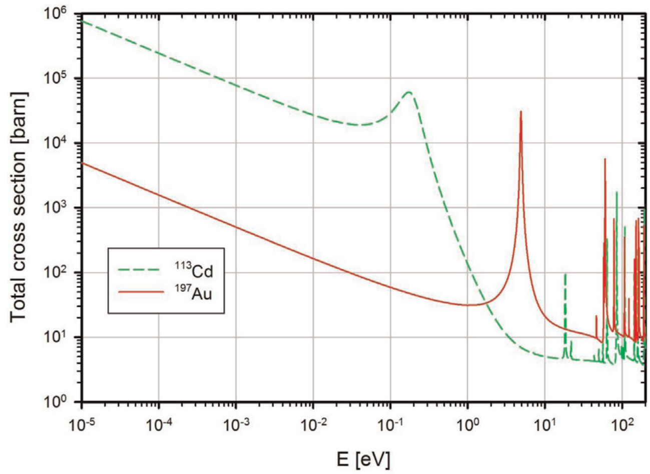

Fig. 1. : Total neutron cross-sections of ^{197}Au and ^{113}Cd.

cross-sections as depicted in Fig. 1. ^{197}Au has a strong resonance at 4.9 eV, which allows the activation of the gold foil inside the cadmium capsule mainly by the epithermal neutrons. Roughly speaking, R_{Cd} and F_{Cd} characterize "contamination" of thermal neutron field with epithermal neutrons.

2. Design of the graphite pile

A new graphite pile, which should serve as a standard source of thermal neutrons, has been built at the Czech Metrology Institute by the VF, a.s. company. Its external dimensions are 1.95 m (W) × 1.95 m (L) × 2.0 m (H). Along the axis perpendicular to the front wall, there is a measurement channel whose dimensions are 0.4 m × 0.4 m × 1.35 m (depth). The channel is equipped with a calibration bench allowing reproducible location of the calibrated device. At the distance of 80 cm from the channel axis, there are six symmetrically located holes for the placement of the radionuclide neutron sources of Am–Be and/or Pu–Be type. The results presented in this work were obtained with three Pu–Be sources placed as illustrated in Fig. 2. Emission rates B of these sources were as follows:

Pu–Be #1: B=8.190E+7 s^{-1} ±0.71% (ref. date 13.5.2010),
Pu–Be #2: B=4.578E+7 s^{-1} ±0.70% (ref. date 14.5.2010),
Pu–Be #3: B=4.893E+7 s^{-1} ±0.71% (ref. date 20.5.2010).

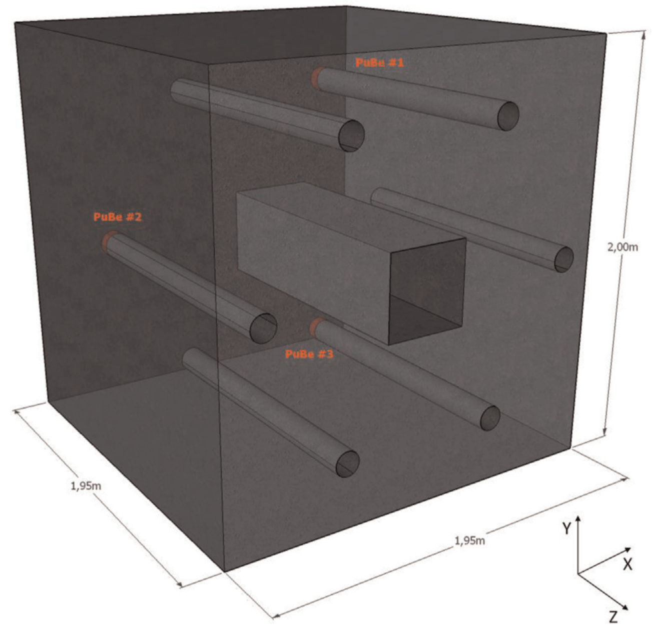

Fig. 2. Model of the graphite pile with the position of the sources marked with red color. The origin of a coordinate system is at the center of the pile. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

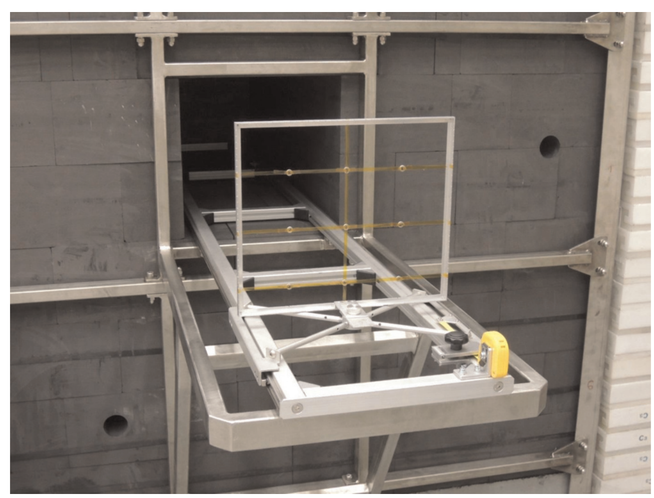

Fig. 3. : An array of nine Au foils placed inside the Cd capsules before their arrangement inside the channel of the pile.

3. Measurement of the thermal neutron fluence rate

3.1. Passive detectors

Thermal neutron fluence rate inside the channel was measured absolutely by activation of gold foils. The foils were 0.1 mm thick, 8 mm in diameter and of 99.99% purity. The foils were irradiated approximately for two days and then their activities were measured with relative uncertainty ~1% using an HPGe detector whose photo-peak efficiency was specified by the method described in (Dryák and Kovář, 2006). The values of thermal fluence rates were determined according to the procedure described in detail in (Technical Report Series no. 107, 1970).

The measurements with gold foils were carried out at two positions (0, 0, −5) cm and (0, 0, 5) cm inside the channel on an array of 3 × 3 foils with 10 cm pitch on the holder shown in Fig. 3. Standard uncertainty of the results summarized in Table 1 is 1%. The mean value of cadmium ratio in the measured positions was R_{Cd}=35.5 and the corresponding cadmium coefficient was F_{Cd} =0.97.

3.2. Active detectors

Measurements by gold foil activation give absolute values of thermal neutron fluence rates, but they are time consuming, hence difficult to use in more detailed investigations of the field homogeneity inside the channel. Therefore, two different active detectors were used for the thermal neutron fluence rate spatial distribution measurement.

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