Characterization of the Graphite Pile as a Source of Thermal Neutrons

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Motivation and Methodology

The absorption cross sections of low energy neutrons obey 1/v law for most materials. Therefore, the detection efficiency of a particular detector increase with decreasing neutron energy. Consequently, most of neutron measuring instruments consist of the detector of thermal neutrons which is located inside of the polyethylene moderator. Development of such instruments requires testing and response calibrations in the field of thermal neutrons. Availability of thermal neutron beams on nuclear reactors is limited and access to them is rather complicated, so it is more convenient to moderate neutrons from the radionuclide neutron sources. Since radiunuclide neutron sources are producing fast neutrons it is necessary to use an appropriate moderator material like heavy water or graphite to thermalize neutrons from the source and to avoid thermal neutron capture in the same time.

Thermal neutron fluence rate is commonly measured by means of gold activation detectors. The quality of a moderated thermal neutron source spectra is then characterized by so called 'cadmium ratio' parameter. This parameter is based on properties of Cd-113 isotope (12.2% natural abundance of Cd) with very high neutron cross-section as depicted in Fig. 1. Gold foil is activated in the thermal neutron field both bare and encapsulated in a Cd housing and the correspondig activity ratio characterize the thermal neutron field. Au-197 has strong resonance at 4.9 eV which allows measurable activation of the gold inside the cadmium capsule.

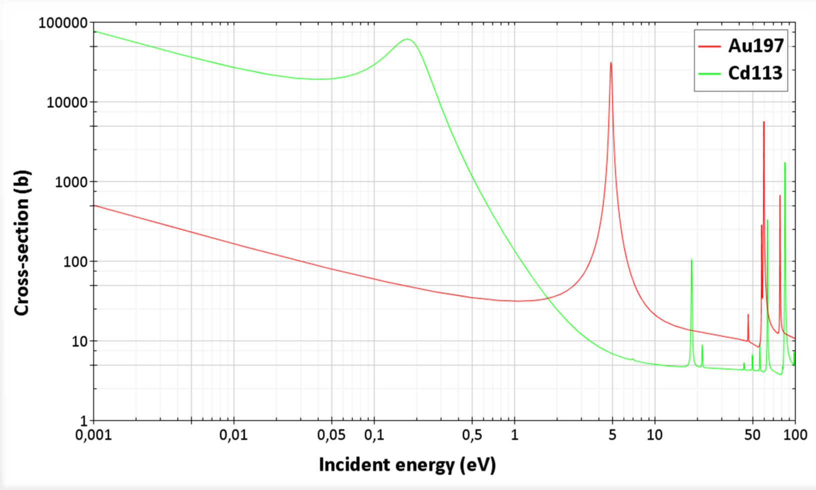

Figure 1: Neutron cross-sections of Au-197 and Cd-113

Basic moderated thermal neutron field characteristics are:

- Cadmium ratio:

$$R_{Cd} = \frac{A_{tot}}{A_{epi}}$$

- Cadmium coefficient:

$$F_{Cd} = \frac{R_{Cd} - 1}{R_{Cd}} = \frac{A_{tot} - A_{epi}}{A_{tot}}$$

where A_{tot} is activity of openly irradiated Au foil and A_{epi} is activity of a Au foil irradiated in the Cd capsule. The effective energy cut-off E_{Cd} of used cadmium covers is 0.5 eV.

Design of the Graphite Pile

A new graphite pile which should serve as a standard source of thermal neutrons has been bulit in the Czech Metrology Institute by the VF, a.s. company. Its actual dimensions are 1.95 m (width) x 1.95 m (lenght) x 2.0 m (height). At the geometrical centre of the front wall, there is a measurement channel whose dimensions are 0.4 m x 0.4 m x 1.35 m (depth). The cavity is equipped with a calibration bench, which enables reproducible location of the calibrated device inside of the channel. At the distance of 80 cm from the cavity axis there are six symmetrically located holes for placement of the radionuclide neutron sources of Am-Be and/or Pu-Be type. The results presented in this work has been taken with three Pu-Be sources placed as depicted in Fig. 2 with the following parameters:

Sources:

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

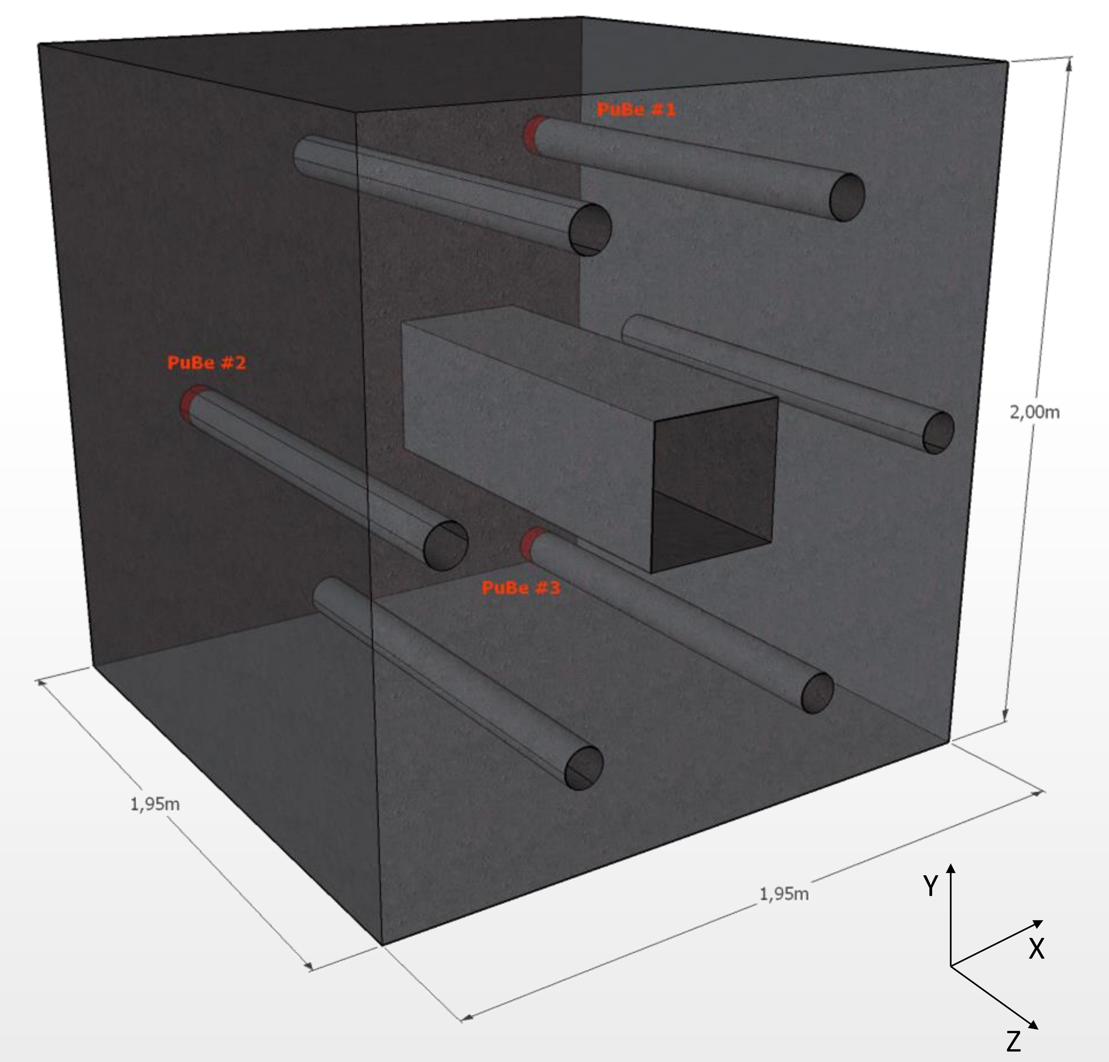

Figure 2: Model of the graphite pile with the position of the sources marked with red color. The coordinate system zero is in the center of the pile.

Absolute Measurement of the Thermal Neutron Fluence Rate

Absolute values of thermal neutron fluence rate were measured by means of gold foil activation. The 0.1 mm thick foils with 8 mm diameter and 99.99% purity has been used. The absolute values were determined in two positions inside of the pile channel on an array of 3x3 foils with 10 cm pitch (see Fig. 3). The mean value of cadmium ratio in the measured positions is R_{Cd} = 35.5 and corresponding cadmium coefficient is F_{Cd} = 0.97.

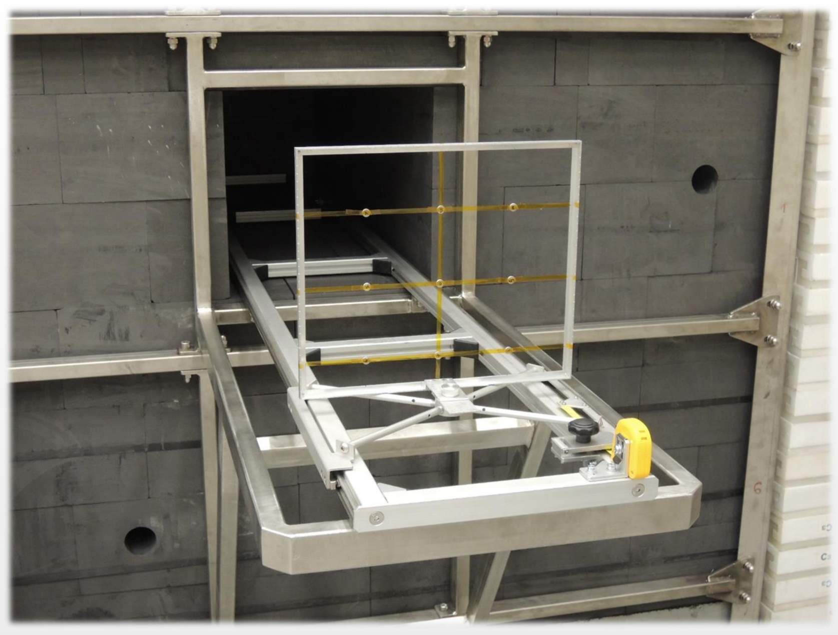

Figure 3: An array of nine Au foils located inside the Cd capsules before placement inside of the thermal neutron channel.

Position X / Position Y	-10 cm	0 cm	10 cm
10 cm	1.989E+04 ± 1.1%	2.011E+04 ± 1.0%	2.043E+04 ± 1.0%
0 cm	1.926E+04 ± 1.1%	1.959E+04 ± 1.1%	2.047E+04 ± 1.0%
-10 cm	1.958E+04 ± 1.1%	1.960E+04 ± 1.1%	1.966E+04 ± 0.9%

Table 1: Thermal neutron fluence rate distribution at the X-Y plane at the position of - 5 cm from the pile center

Position X / Position Y	-10 cm	0 cm	10 cm
10 cm	2.004E+04 ± 0.9%	1.990E+04 ± 1.1%	2.075E+04 ± 1.0%
0 cm	1.975E+04 ± 1.0%	1.981E+04 ± 1.0%	2.004E+04 ± 1.1%
-10 cm	1.962E+04 ± 1.1%	1.933E+04 ± 1.1%	1.988E+04 ± 1.0%

Table 2: Thermal neutron fluence rate distribution at the X-Y plane at the position of 5 cm from the pile center towards the channel opening

Map of the Thermal Neutron Fluence Rate Along the Cavity Axis

Measurement of the gold foil activation gives absolute thermal neutron fluence rates but it is time consuming and thus difficult to use for more detailed measurement of the field homogeneity inside of the pile cavity.

For more detailed measurement we have used two different active detectors:

- Silicon pixel detector Timepix equipped with B-10 converter:

n + ^{10}B → α (1.78 MeV) + ^{7}Li (1.01 MeV) + γ*

- He-3 gas proportional counter NH05:

n + ^{3}He → p (0.57 MeV) + ^{3}H (0.19 MeV)

The results of the measurement are presented in Fig. 4 together with the prediction from MCNPX simulation. The results obtained with the active detectors were converted to thermal neutron fluence rates using values measured with activation gold foils.

The results of both experiments and simulation show that thermal neutron fluence rate decrease of about 5% at distance of ± 20 cm from the pile center.

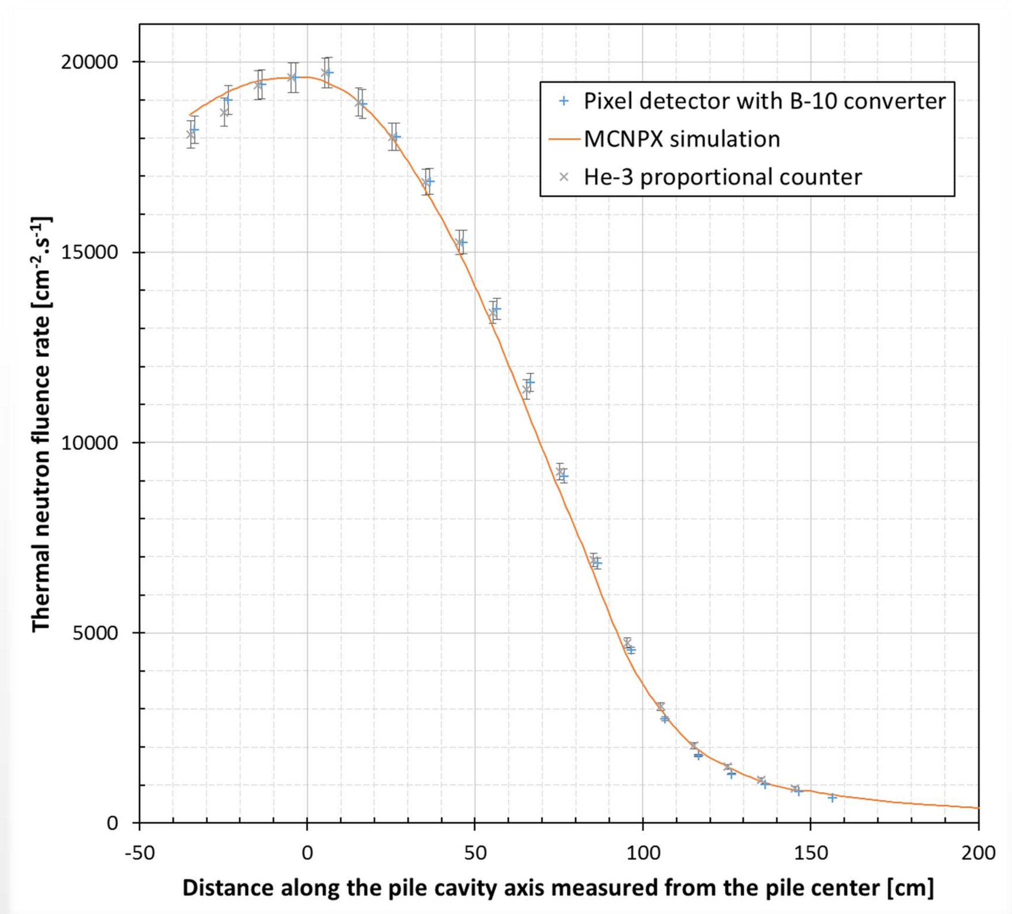

Figure 4: Measurement of the thermal neutron fluence rate along the cavity axis by two different active detectors and it's comparison with the simulation. The pile cavity edge is at the distance of 97.5 cm from the center.

Measurement and Simulation of the Field Homogeneity

The measurement of the thermal neutron fluence rate along the pile cavity axis well demonstrate good agreement of the MCNPX simulation with experimental data. The same simulation has been used to determine the field homogeneity over the X-Y planes perpendicular to the cavity axis at various Z distances.

Figure 5 show the homogeneity of the thermal neutron field at the central X-Y plane of the pile channel. The thermal neutron fluence rate fluctuate only within ± 5% at 94% of the plane area. The most deviated points are in the upper left corner of the cavity where the strongest Pu-Be source #1 is located.

Evaluation of the field distributions predicted by the simulation at various other positions along the Z axis show that the 5% homogeneity criteria is fulfilled in the cylindrical volume 40 cm in diameter around the cavity axis at Z positions between ± 20 cm from the pile center.

The design of the pile allows to change the position of the sources among 6 available openings. The configuration where the Pu-Be source #1 will be located opposite to the sources #2 and #3 will be investigated in next experiment.

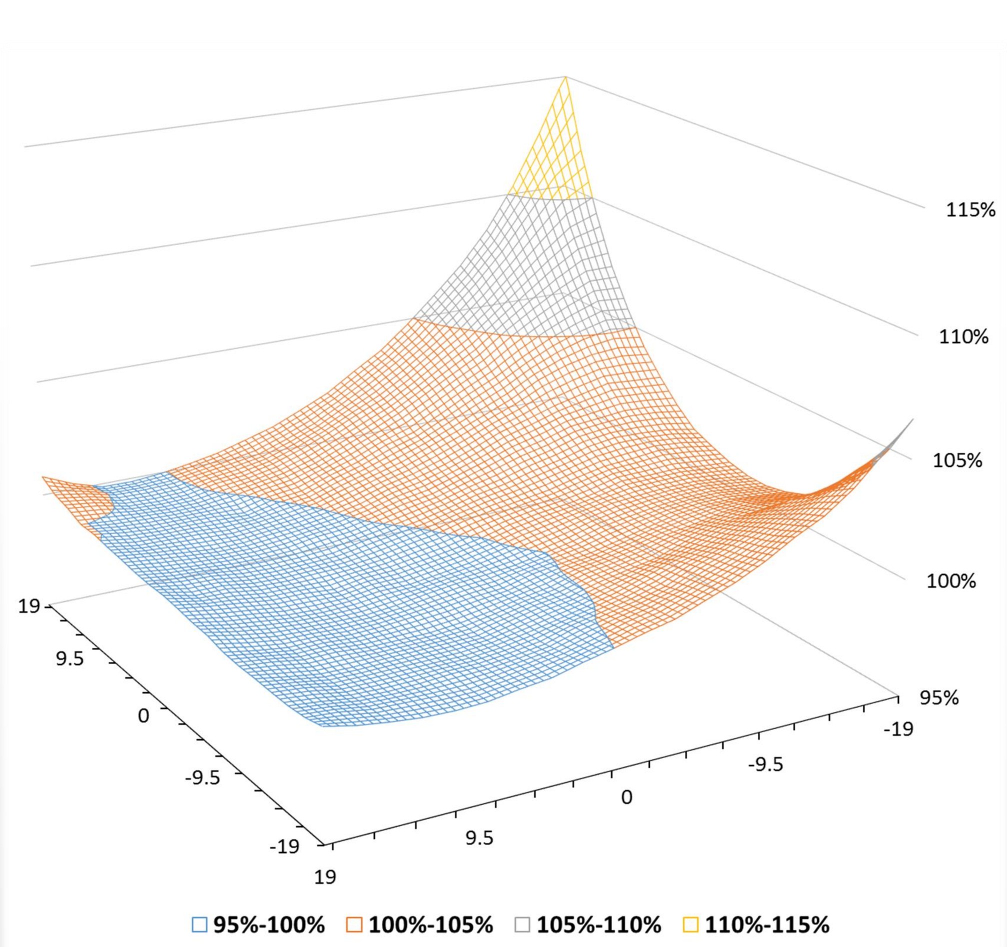

Figure 5: Simulation of the thermal neutron fluence rate homogeneity at the X-Y plane at the central position of the pile channel. The thermal neutron fluence rate fluctuates within ± 5% at 94% of the evaluated area.

Summary, Application and References

General features of the thermal neutron source:

A standard source of thermal neutrons in a form of graphite pile has been built in the Czech Metrology Institute by the VF, a.s. company. The pile has been designed with high flexibility and it can accommodate up to 6 aluminum rods containing one or more fast neutron sources. Absolute thermal neutron fluence rate and homogeneity has been measured for one particular Pu-Be sources configuration (see Fig. 2) with the following results:

- Channel dimensions: 40 cm x 40 cm x 135 cm (depth)
- Thermal neutron fluence rate: 1.97E+04 $cm^{-2}.s^{-1}$ (± 1.1%)
- Area of ± 5% thermal neutron fluence rate homogeneity: Cylinder of 40 cm in diameter and 40 cm in height centered in the pile geometrical center and oriented along the cavity axis
- Mean cadmium ratio: 35.5
- Mean cadmium coefficient: 0.97

Applications:

Absolute calibration of the detectors of thermal neutrons is a main application of the pile. The design of the pile allows to change the position of the sources and thus vary with the thermal neutron field parameters within reasonable boundaries, i.e. to maximize field homogeneity or to generate defined field gradient for calibration of large volume neutron detectors.

- Calibration of Medipix and Timepix multilayer detectors for measurement of the radiation field spectral composition at the ATLAS experiment at CERN.
- Calibration of silicon single-pad detectors with B-10 doping for European Space Agency (ESA).
- Calibration of Timepix detectors with Li-6 converter for National Aeronautics and Space Administration (NASA) – used on board of International Space Station (ISS).