Optimization of “Romashka" setup for investigation of (n, n'γ)-reactions with tagged neutrons method

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Abstract

To investigate the angular distribution of γ-rays from the inelastic scattering of 14.1 MeV neutrons on some important for basic and applied nuclear physics atomic nuclei, a number of simulations and experiments has been done at Frank Laboratory of Neutron Physics (FLNP) of the Joint Institute for Nuclear Research (JINR) in Dubna. As a result, a geometry for the experimental set-up providing optimal angular resolution and efficiency for registration of γ-ray was established. Here we present some results on the amplitude- and time- distributions of γ-rays from the inelastic scattering of 14.1 MeV tagged neutrons from pure carbon cubic samples for the suitable geometry. The data on the anisotropy of 4.44 MeV characteristic γ-rays from the reaction $^{12}C(n,n'\gamma)^{12}C$ will be published after finalizing the data analysis.

Keywords: Gama-ray spectrometry, NaI(Tl), “Romashka” multi-detector system, Tagged neutron method, TANGRA-setup, Inelastic neutron scattering

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1. Introduction

The study of rare processes occurring as a result of the interaction of 14.1 MeV neutrons with medium and heavy nuclei (the (n, n'), (n, n'γ), and (n, 2n') reactions) is one of the primary lines of research in TANGRA (Tagged Neutrons & Gamma Rays) project [1].

First to be measured are the angular correlations between gamma-rays and neutrons from the inelastic scattering of 14.1 MeV neutrons with carbon nuclei: $^{12}C(n,n'\gamma)^{12}C$-reaction. Since the yield of this type of reactions is small, one is generally faced with the problem of suppressing the neutron background produced by neutrons that penetrate directly from the source into scintillation detectors that are used to detect secondary nuclear radiation (neutrons and gamma quanta). It is important that the passive shielding of scintillation detectors from the direct impact on them of neutrons from the source be optimized.

Recently, some methodological work in the frame of TANGRA-project has been done at the Joint Institute for Nuclear Research (Dubna, Russia) and the optimal geometry for investigation of the inelastic scattering of 14.1 MeV neutrons on carbon sample was determined.

As a source of neutrons a FSUE VNIIA portable neutron generator ING-27 (Fig. 1, left) is used [1]. The 14.1 MeV neutrons are produced in D-T fusion-fission reaction:

$$D + T \rightarrow \alpha + n, \quad Q = 17.59\ MeV \tag{1}$$

The incorporated in ING-27 vacuum chamber 64-pixel α-sensor permits to "tag" and count every neutron, because the both reaction products are irradiated nearly collinear in opposite directions.

For detection of the inelastic scattered neutrons and gamma-rays, a multi-detector system of "Romashka" type (Fig. 1, right) is intended to be used [1, 3].

Fig. 1. Portable neutron generator ING-27 (left) and "Romashka" base setup of 24 NaI(Tl) scintillation gamma-ray detectors (right).

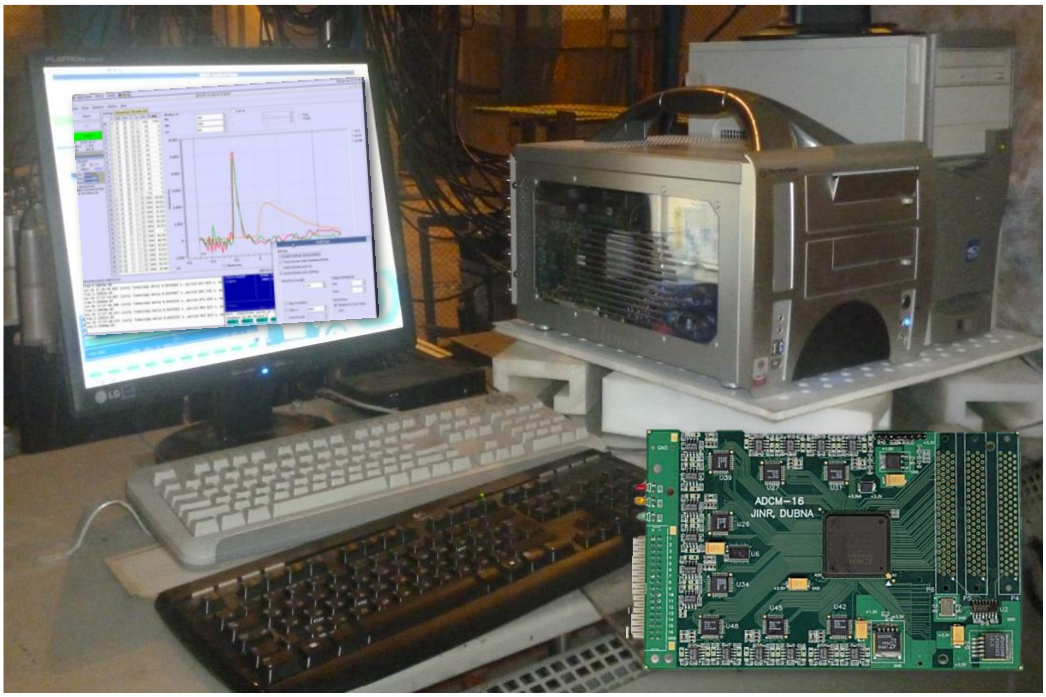

Fig. 2. Data acquisition system: MCA ADCM and its software main panel.

The versatile Al construction permits many detectors of gamma-rays (neutrons) to be arranged in different configurations. At present, up to 24 Amcrys© hexagonal NaI(Tl)-detectors can be used.

The signal processing and data collecting with “Romashka” was done by a computerized 32-channel digital readout system, utilizing two ADCM16-LTC (16-channel/14-bit/100MHz) ADC-boards from AFI Electronics© [3].

Using double (α-γ)-coincidences one can achieve “effect/background”-ratio of ~ 200.

Here the results from the measurements and model calculations performed to optimize the geometry of the setup are presented.

2. Measuring conditions and experimental results

To find the optimal arrangement of ING-27, “Romashka” and the shielding-collimator [4], three different configurations (geometries) G1, G2 (Fig. 3) and G3 (Fig. 4), were tested:

Geometry G1: 20 NaI(Tl) detectors are arranged horizontally on a ring in which geometrical center a carbon target (graphite cube) was situated. The distance between (center of) the target and the front-end of the detectors were r ≈ 50 cm; the distance between the target and ING-27 n-source was L ≈ 110 cm; the thickness of the iron (Fe) shielding-collimator was d ≈ 50 cm;

Geometry G2: the same as G1 with L ≈ 100 cm, d ≈ 50 cm, r ≈ 35 cm.

Geometry G3: 22 NaI(Tl) arranged vertically with L ≈ 84 cm, d ≈ 40 cm, r ≈ 32 cm.

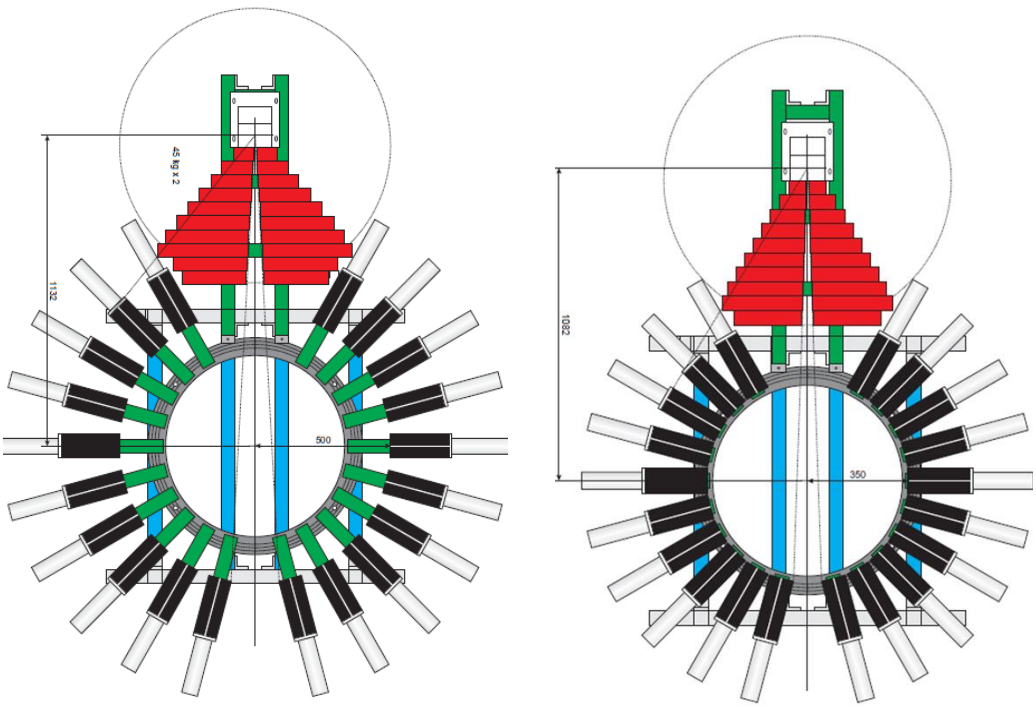

Fig. 3. TANGRA setup test configurations (top view, details in the text):
G1(left): L ≈ 110 cm; d ≈ 50 cm, r ≈ 50 cm; G2 (right): L ≈ 100 cm, d ≈ 50 cm, r ≈ 35 cm.

With ING-27 neutron tagged beam “on”, for all the three source-detector configuration geometries, the gamma-ray pulse-height- and time- spectra were measured by NaI(Tl) detectors.

The time- and energy- distributions of the counts from one of the γ-detectors (3 in Fig. 4) situated at angle θ =15º, in coincidence with the counts from the α-detector central pixel, were measured.

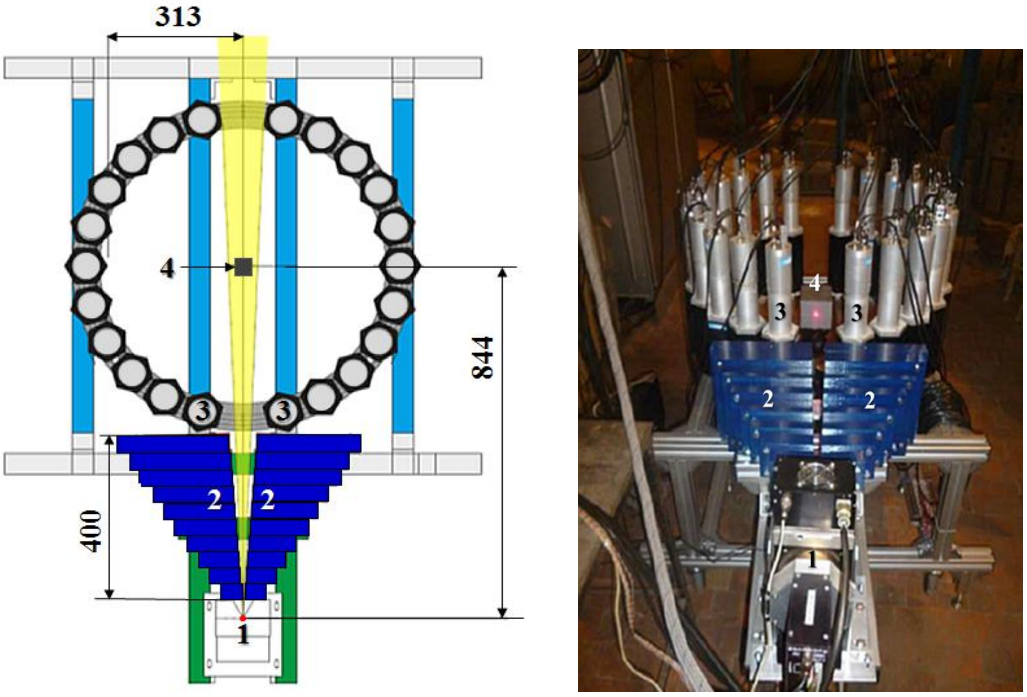

Fig. 4. The scheme of G3-geometry (left) and photo (right) of the “source-detector” part of the experimental setup: 1 – neutron source ING-27, 2 – iron shield-collimator of neutrons and γ-rays, 3 – NaI(Tl) scintillation detectors of γ-rays and neutrons, 4 – carbon ^{12}C target sample. The main dimensions in the scheme are shown in millimetres; 22 NaI(Tl) arranged vertically, L ≈ 84 cm, d ≈ 40 cm, r ≈ 32 cm.

For every geometry 2 hours long pair (effect, background) measurements were done: with the carbon 10x10x10cm C-cube in the tagged beam (reaction effect) and one without it (background radiation effect). The results are shown in the Figs. 5–7 bellow.

As an example, the bulk time- and amplitude- distributions of events, recorded 2 hours with C-cube for each of the three geometries, are shown in Fig. 5 left and right, respectively.

The gamma-rays pulse-time spectra shown in the time-interval from 175 ns to 210 ns (Fig. 5, left) are the result of all the interaction of the shielding (and environment materials) scattered neutron- and gamma- radiation with NaI(Tl) probe.

For the whole time interval, the gamma-rays pulse-height spectra (number of events per amplitude channel) are shown as a function of the light output (LO) of the NaI(Tl) scintillator in MeVee unit (equivalent to 1 MeV electron light output) (Fig. 5, right). We discriminated gamma-ray events with light output bellow ~0.2 MeVee. Despite of the moderate energy resolution of NaI(Tl) gamma-detector, the peaks corresponding to the gamma-rays with characteristic energy

of 4.44 MeV from the inelastic scattering of 14.1 MeV neutrons on the ^{12}C nuclei, as well as the single escape peaks, are clearly seen.

From these spectra one can conclude also that the geometry G3 provides a highest efficiency of registration of the gamma-rays comparing to the other two geometries of the experimental setup.

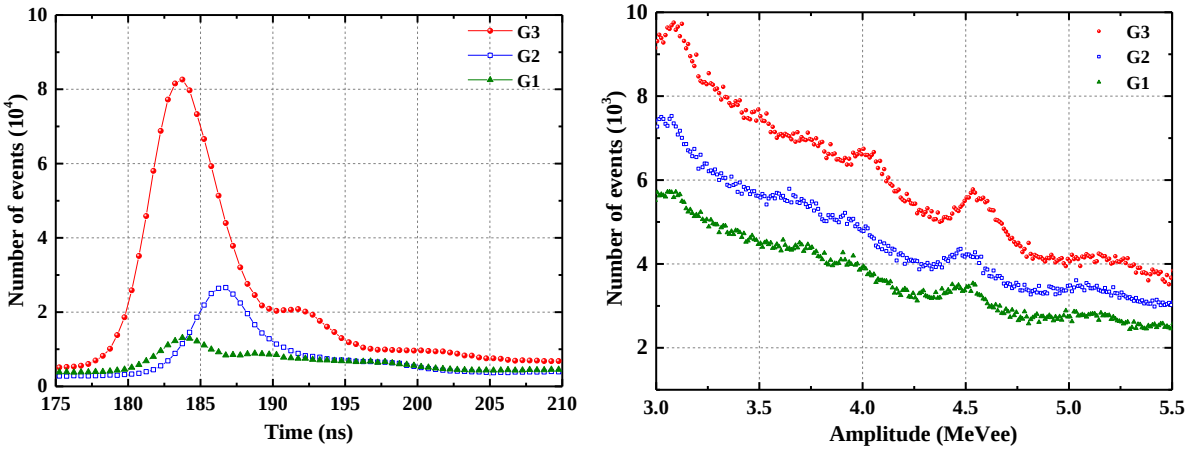

Fig. 5. The bulk time- and amplitude- distributions of events (left and right, respectively) recorded with C-cube for the three geometries of the experimental setup.

Using a NaI(Tl) light output gate of (3–5.5) MeVee (Fig. 5, right), we obtained the time-distributions of the recorded events with C-cube (Fig. 6, left) in the center of "Romashka" and without it (Fig. 6, right). The peak around 192.5 ns (Fig. 6, left) can be interpreted as a contribution of the gamma-rays from the $^{12}C(n,n'\gamma)^{12}C$-reaction.

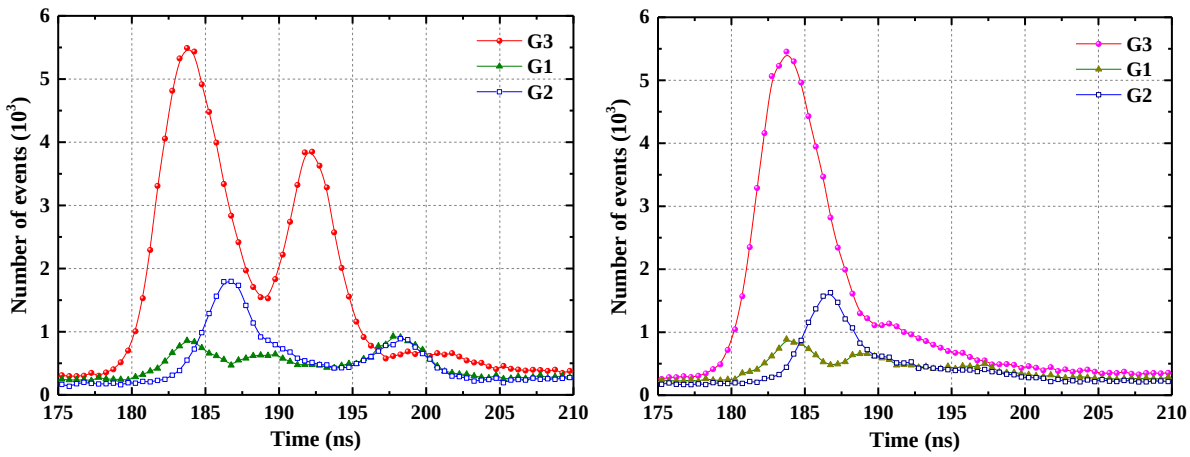

Fig. 6. Time-distributions of recorded events in the amplitude interval 3–5.5 MeVee for the three types of the experimental geometry with C-cube (left) and without it (right).

Using a (188–204) ns time gate (Fig. 6, left), we obtained the corresponding gamma-rays pulse-height spectra (amplitude distributions) in the LO-interval of (3–5.5) MeVee with C-cube (Fig. 7, left) and without it (Fig. 7, right).

In Fig. 7 (left) the signature of the gamma-rays from the $^{12}C(n,n'\gamma)^{12}C$ reaction is clearly seen: 4.44 MeV gamma-rays full-energy peak at ~ 4.5 MeVee, one gamma-quantum (single) escape peak at ~ 4.0 MeVee and two gamma-quanta (double) escape peak at ~ 3.5 MeVee.

In Fig. 7 (right), without C-cube in, the signature of the gamma-rays from the $^{12}C(n,n'\gamma)^{12}C$ reaction is still observable, because of the exciting of some C-containing materials in the vicinity of the experimental setup. This result shows the importance of the background radiation conditions and the environment itself on the accuracy of the data obtained in such kind of experiments.

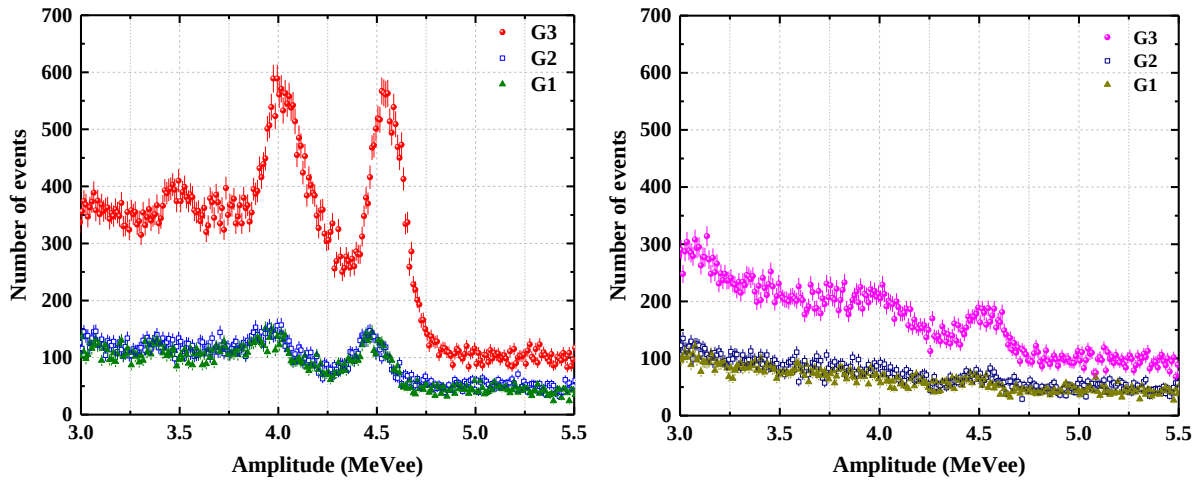

Fig. 7. Amplitude distributions of events recorded in the time interval from 188 ns to 204 ns for the three experimental setup geometries with C-cube (left) and without it (right).

In order to estimate the angular resolution of a single NaI(Tl) probe in tested experimental setups, as well as the intensity of the gamma-radiation with energy 4.44 MeV from the $^{12}C(n,n'\gamma)^{12}C$-reaction with 14.1 MeV neutrons when using C-cubes of different size (volumes), a number of Monte-Carlo simulations was done using Geant4 software package [5].

The simulated angular distributions of the gamma-rays with energy 4.44 MeV, arising from the inelastic scattering of 14.1 MeV neutrons in a C-cube with dimension 5x5x5cm, registered by a single hexagonal NaI(Tl) probe of the evaluated experimental setups, are shown in Fig. 8 (left).

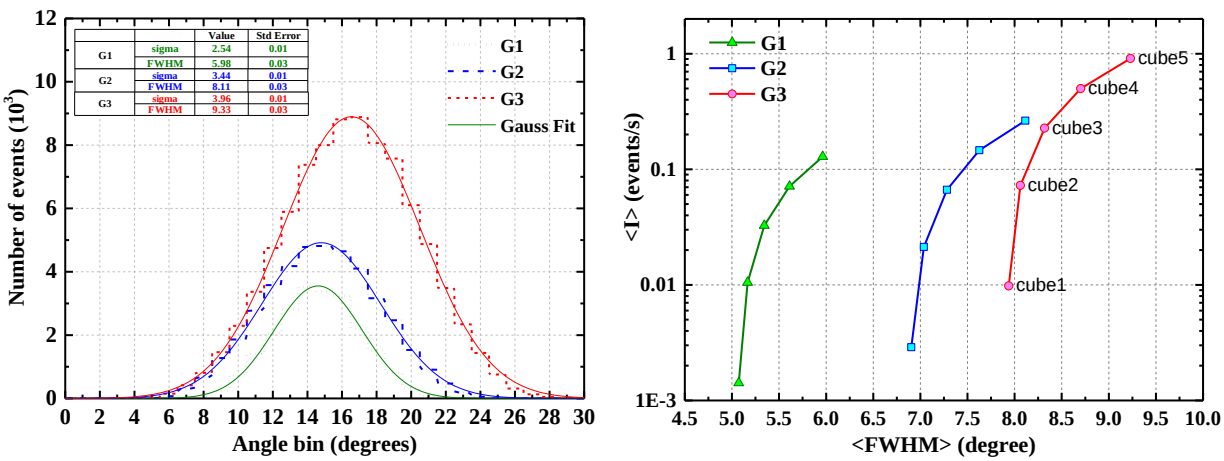

Fig. 8. Geant4 simulations of NaI(Tl) gamma-ray detector angular resolution for test geometries with 5x5x5cm C-cube inside the tagged neutron beam (left) and expected number of 4.44 MeV photo-peak pulses for the test geometries with various C-cube length equal to 1, 2, 3, 4, and 5 cm (right).

In Fig. 8 (right) is shown the dependence of the NaI(Tl) probe 4.44 MeV gamma-ray expected average count-rate <I> on the size of the C-cube and experimental setup geometry.

From the both figures one can conclude that the most optimal as count-rate and resolution is using a 5x5x5cm C-cube and G3-geometry of the experimental setup.

3. Conclusions

On the base of results obtained experimentally and by Geant4 [5] simulations, the following conclusions, concerning the building of an optimal (as efficiency and resolution) experimental setup for the investigation of inelastic scattering of 14.1 MeV neutrons with ^{12}C, can be made:

1) The shielding of NaI(Tl) detectors can be constructed from iron (Fe) plates with a total thickness of 40 ÷ 50 cm.
2) The geometry G3 of the experimental setup provides the best efficiency for γ-ray registration, comparing to G1 and G2 ones, while preserves a better time resolution;
3) The angular resolution (FWHM) simulated with Geant4 for all the geometries falls within 5° – 9° interval.

Based on this we are proposing the G3-configuration as optimal for studying of the angular distributions of gamma-rays from the inelastic scattering of 14.1 MeV neutrons in carbon.

Acknowledgements

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References

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