Simulation experiments for direct dineutron decay observation

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Abstract

- In our previous studies, possible and statistically significant observations of a bound dineutron in nuclear reactions with fast neutrons on ^{159}Tb [1] and ^{175}Lu [2] nuclei were reported and discussed, that correspond to Migdal's and Dyugaev's [3, 4] predictions about bound dineutron formation within the potential well but outside of volume of host nuclei.
- To directly observe the decay of bound dineutrons, the calculations of half-lives and the end-point energy for the dineutron decay were made [5, 6].
- In addition, some suggestions for the future experiment for direct observation of bound dineutron decays were discussed in [7] along with the list of the nuclei as possible candidates, on which a bound dineutron could be observed in the experiments [8, 9].
- In this work, we developed and tested the simulation model for the future experiments proposed in [7] for the observation of bound dineutron decays in neutron induced nuclear reactions on nucleus from the lists in [8, 9].
- The difference between the detected beta-spectrum with and without formation of dineutrons with the thorough consideration of gamma-rays emitted from residual nuclei can be directly considered as the sign of the formation of a bound dineutron followed by its decay.
- The scheme of dineutron decays via to the Gamov-Teller or Fermi transitions with the known decay schemes of residual nuclei are used for the simulation.
- The estimates of the the cross-sections of bound dineutrons formation on rare earth nuclei were taken into account.

Sample "irradiation" for the dineutron observation

- The framework to plan activation method-based experiments in low-energy nuclear physics has been developed. It utilizes Geant4 [10], TALYS [11], and scripts of Python.
- The framework calculates partial activities in the sample by employing reaction cross sections computed in TALYS.
- The calculated activities are employed to simulate the time flow of initial events.
- The sample of ^{169}Tm was "irradiated" with neutrons of E_n= 6.2 MeV and E_n= 7.5 MeV average energies with the neutron flux 6.2×10^6 n/(cm$^2\times$s), the irradiation time was 4,860 s, cooling time before sample countings was 600 s and live time of the measurement for detector system (Fig.1) was 5,000 s.
- After irradiation, the following isotopes were produced according the TALYS calculations: ^{170}Tm, ^{169}Er, ^{166,166m,165}Ho, ^{165}Dy, ^{162}Tb with their cross-section production estimated by TALYS.
- The formation of ^2n was stated with the cross-section of 30 mb based on previous experimental observations and predictions.
- The following properties of dineutron were used:
  - the dineutron is a bound nucleus in the singlet state;
  - the binding energy: $B_{dn} \lesssim 2.5$ MeV;
  - the decay mode: $^2n \rightarrow d + e + \widetilde{\nu_e}$
  - the pure beta emitter,
  - the end-point energy of the β^--spectrum: E_{max}= 0.54÷0.56 MeV;
  - the half-lives of the dineutron decay:
    - for the Gamov-Teller transition equals 1,215 s;
    - for the Fermi transition equals 5,877 s.
- The dineutron decay was emulated via ^{170}Tm decay with a modified half-life corresponding to ^2n decays (1,215 s - for the G-T transition, and 5,877 s - for the Fermi transitions).

Simulation of the experiment for detection of ^2n beta-decay

- In Geant4, the detectors' event streams are computed based on the initial event stream, from which the anti-coincidences are simulated and spectra generated.
- The framework utilizes time streams to model the experiment's delay time.
- The "irradiated" samples were placed next to a thin plastic organic scintillator for detection of electrons due to dineutron decay in 2π geometry and surrounded by two BGO detectors (Fig.1) for detection of the emitted gamma-rays from nuclear reaction products.
- Detectors and corresponding circuits may operate both in coincidence and anticoincidence modes.
- The difference between the detected beta-spectrum with and without formation of dineutrons taking into account gamma-rays emitted from residual nuclei, can be the directly treated as the observation of dineutron decays.

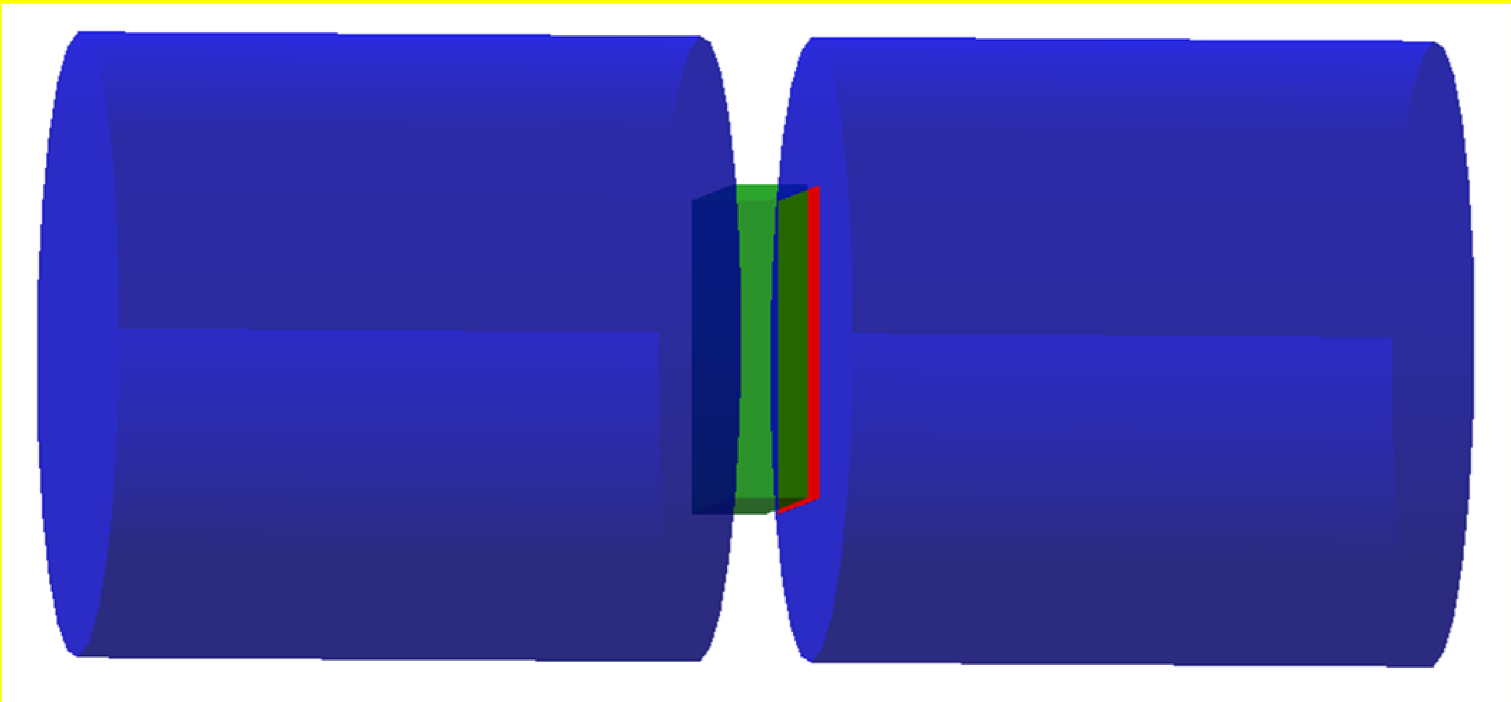

Fig.1. Detector system geometry: "irradiated" sample ^{169}Tm (red) – dimensions: 24 × 24 mm, thickness: 50 μm, weight: 0.268 g; beta-detector (green, organic scintillator)– dimensions: 24×24×6 mm; gamma detectors (blue, anti-coincidence) BGO – dimensions: 50 × 50 mm

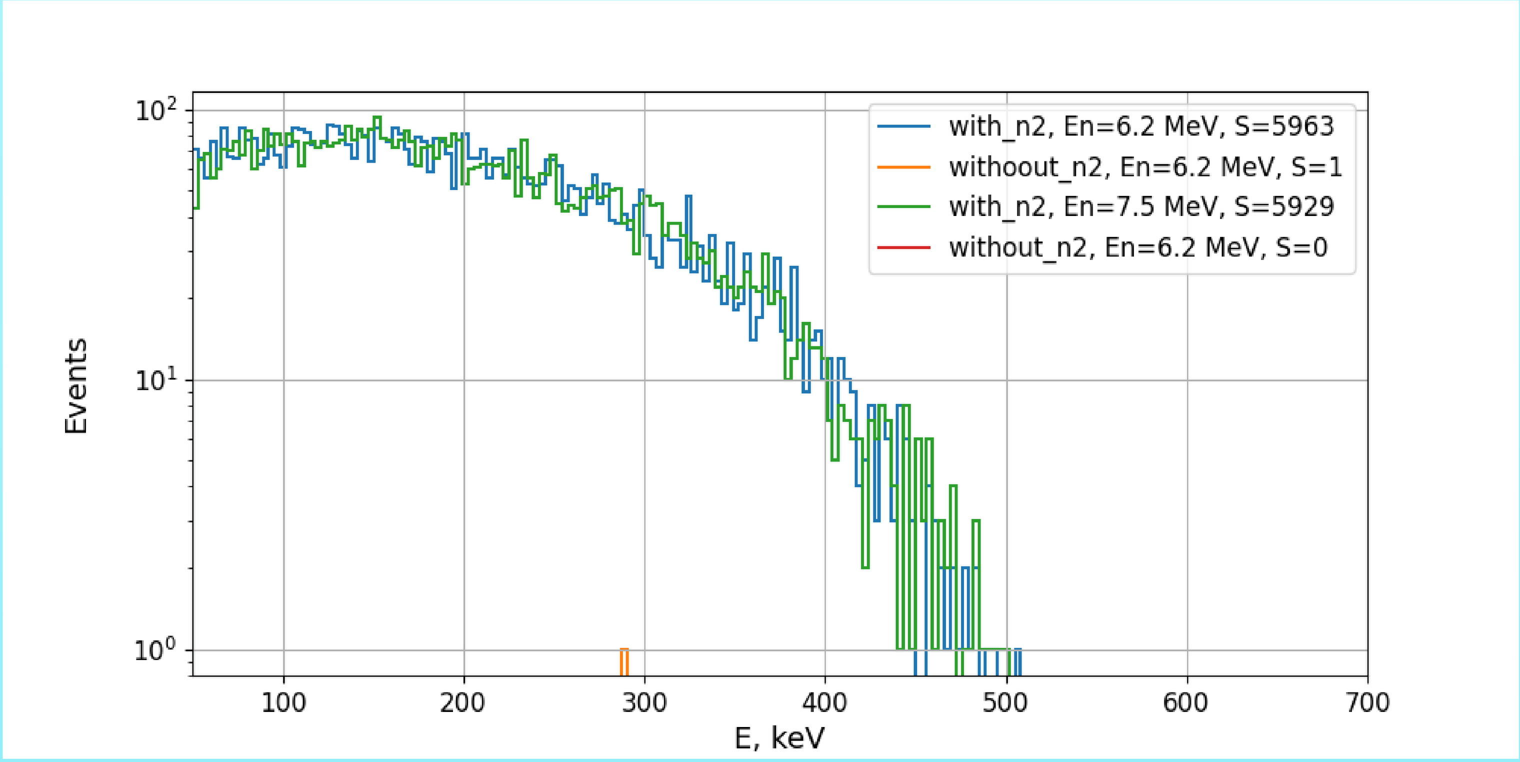

Fig 2. Detection of the GT-transition ^2n beta-decay in the organic scintillator based on Geant4 simulation. Irradiation time is 4,860 s. The half-live of the dineutron decay is 1,215 s. The ratio of the signal with ^2n to the signal without ^2n is nearly 5.6×10^4 for "irradiation" of ^{169}Tm sample with 6.2 and 7.5 MeV neutron energies.

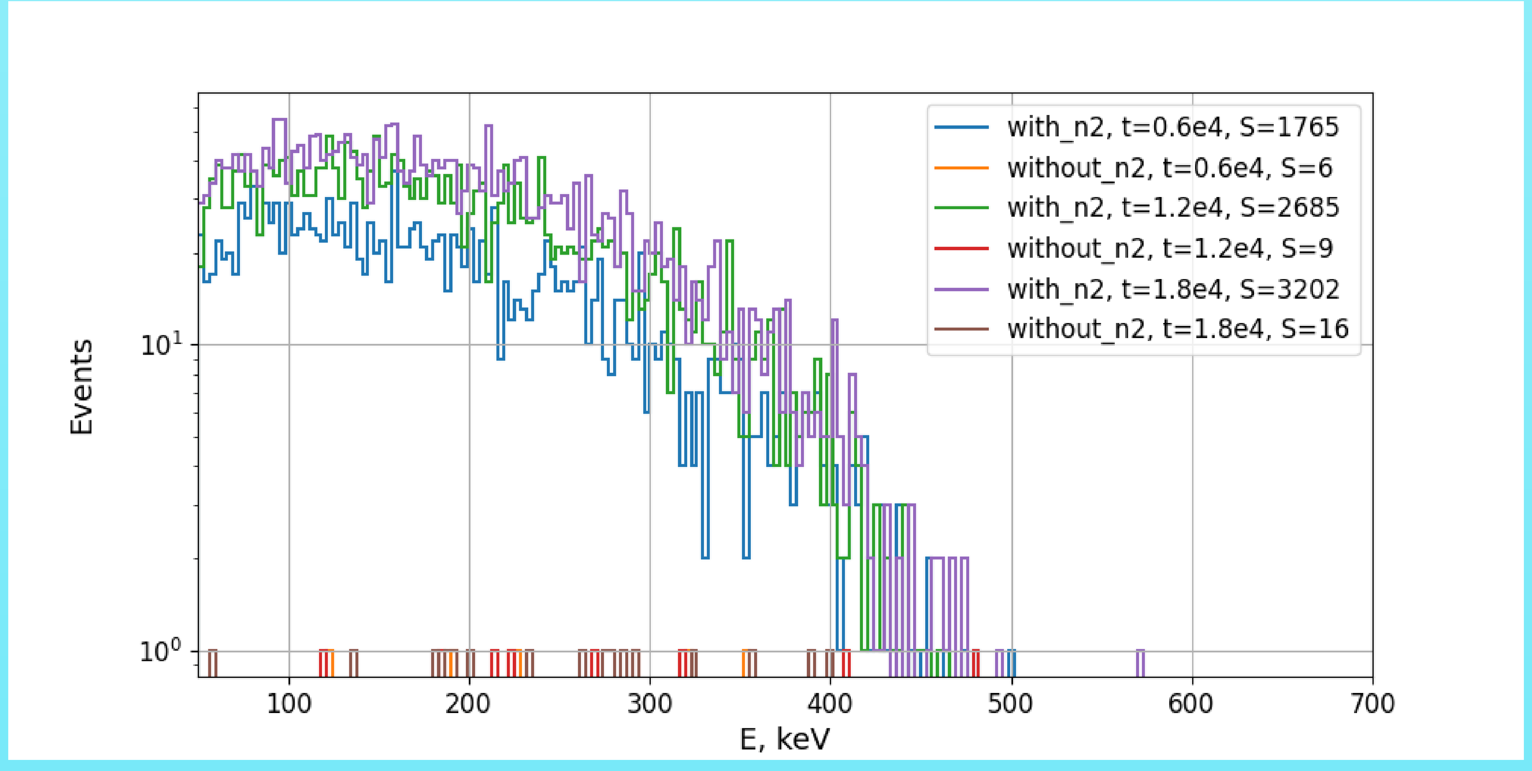

Fig 3. Detection of the F-transition ^2n beta-decay in the organic scintillator based on Geant4 simulation. Irradiation time is 18,000 s. The half-live of the dineutron decay 5,877 s. The ratio of the signal with ^2n to the signal without ^2n is within 200-300 for different counting times: 6,000 ÷ 18,000 s. The impinging neutron energy on ^{169}Tm sample: 7.5 MeV.

Conclusions

- ^{169}Tm is considered as one of the very promising target nuclei for a direct observation of dineutron decay because of strong evidence in beta-spectrum detection in proposed detector system.
- It is shown that the beta-spectrum due to the GT- transition of bound dineutron decays with the 1,215 s half-life can be detected for the neutron energies of 6.2 and 7.5 MeV
- It is shown that the beta-spectrum due to the F- transition of bound dineutron decays with the 5,877 s half-life can be also detected for the neutron energy of 7.5 MeV
- On the basis of the simulated experiment results, the future experiments with a more precise estimate of reaction cross-sections will be designed, and the corrections to the model of bound dineutron formation in nuclear reactions will be made.

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