DEVELOPMENT OF A LOW BACKGROUND PULSED GENERATOR OF INTERMEDIATE ENERGY RANGE NEUTRONS FOR REMOTE DETECTION OF FISSILE MATERIALS [*]

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A structure of radiation shielding for a low background pulsed generator of intermediate energy range neutrons was developed on the basis of calculations and the data obtained in the model experiments, and limit parameters for remote detection of fissile materials using this generator were determined and are presented in this paper. The magnetically insulated diode structure and the radiation shielding geometry were optimized in accordance with the performed calculations.

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1. INTRODUCTION

Topicality of solving the problems of fissile material reliable detection demands some new active methods to be developed. One of such active methods is the technique of pulsed illumination of an object with neutrons of intermediate energy range. Examples of sub-MeV neutron utilization for ^{235}U and ^{239}U detection and recognition were described in a number of papers [1,2]. However, in all the described experiments the source, object, and detector of the induced radiation were positioned close to one another. But the use of a high-power pulsed source allows to position it at some distance from the object under examination and to use the time-of-flight technique for the object recognition.

Principal feasibility as well as the advantages of using the technique of an object illumination with a high-power pulse of sub-MeV neutrons for fissile material remote detection is discussed in [3].

Preliminary modeling experiments carried out at the High-Current Electronics Laboratory of Kharkiv National University have shown especial promise of the proposed technique [4]. The technique provided effective recording of the signals induced by scattering neutrons of the model probing pulse, simulating fission neutrons, at the distance of some meters.

The factors limiting the technique potentialities that were found out during the experiments may be accounted mainly for the radiation background effect on the detectors produced by the neutron generator. The neutron generator operation was accompanied by intensive radiation background resulting from both the bremsstrahlung radiation of electron component of the ion diode current and the nuclear reactions induced by an ion beam and neutrons.

To achieve effective remote probing a high-power pulsed neutron source with low radiation background is required. This paper is devoted to the problem concerned with the research and development of a sub-MeV neutron generator of this kind.

2. NEUTRON GENERATOR

The generator of high-power neutron illumination pulses can be built on the basis of a high-current pulsed proton accelerator with using $Li^7(p,n)Be^7$ and $T(p,n)^3He$ reactions. For the comparable neutron yields from these reactions, realization of the generator based on the use of the first ($Li^7(p,n)Be^7$) reaction has some disadvantages:

- to build a 2.2-MeV magnetically insulated diode is more difficult;
- to attenuate bremsstrahlung background at a higher quantum energy is more difficult;
- the neutron pulse spectrum is more spread-out than when the generator operates using the second ($T(p,n)^3He$) reaction.

Therefore, the neutron generator under development is based on the $T(p,n)^4He$ reaction. Some other nuclear reactions allowing to generate neutron pulses may also be used at the stage of the facility adjustment and model experiments.

The $T(p,n)^3He$ reaction-based neutron generator operation is accompanied by essential (of the order of 0.035%) γ-quanta yield at the energy of 20 MeV from the $T(p,\gamma)^4He$ reaction [5]. It is known as well, that deuterium natural occurrence is 0.01%, and so, the $T(d,n)^4He$ reaction may yield 10^7 neutron/pulse with the energy of 14 MeV at the proton beam current of 50… 100 kA.

The greater portion of the generated neutron flow may also cause background when directly hitting the detector or being converted into γ-quanta of radiation capture on the device structural units (see Fig.1, curve ***2***).

Depending on the scintillator irradiation dose rate the scintillator luminescence intensity may be strong enough and prevent the response signal from being recorded (see Fig.1 curve ***1***).

Various versions of radiation shielding were tried in the experiments. As a rule it was made of alternate layers of paraffin, lead, and polyethylene.

Operation efficiency of shielding of this kind may be seen from comparison of curves ***2*** and ***3*** in Fig.1.

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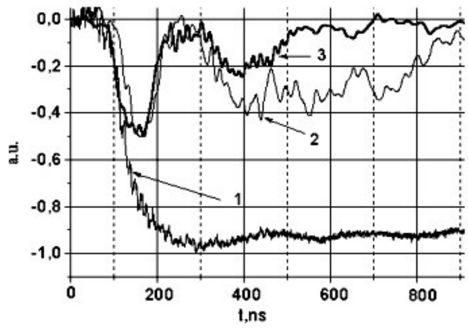

*Fig.1. Shapes of the scintillation detector response signals: **1** – signal measured without shielding; **2** – signal detected after the lead shielding between the detector and the generator had been mounted; **3** – neutron response signal clearly seen after the background neutron shielding had been mounted*

The following requirements to the neutron generator were worked out on the grounds of the accumulated experimental data:

- Maximally narrow neutron energy range *(En ≈ 350 keV)*
- Neutron output per pulse should be no less than 10^9 neutron/pulse;
- The levels of radiation background and bremsstrahlung must not exceed the response signal value at the points where the response signal detectors are placed.
- The generator must provide stable neutron pulse characteristics during a long period of its operation.

According to the requirements to the neutron pulse the tritium target should contain no less than $1.69\cdot 10^{19}$ nuclear/cm^2. The proton beam energy is to be 1.2 MeV, its current – 50 kA, and pulse duration ~100 ns.

High-performance ion diode insulated by the external magnetic field will provide parameters specified for the proton beam.

3. RADIATION BACKGROUND CALCULATION

To reduce the electron escape in the diode, which can induce bremsstrahlung, diode fields were calculated, and electrode geometry was determined, as well as demands to the insulating field producing coils were defined.

Simulation of electron trajectories in the ion diode allowed determining the most probable places for the electrons to hit the structural units. Because of the necessity to reduce the bremsstrahlung background these parts of the diode must be made of low-Z materials. Moreover, all the unfilled places in the diode must be filled with materials that would efficiently decrease the radiation background, i.e., borated polyethylene and lead. The gamma-background produced in the process of the unused neutron interaction with the generator units, most of all with those made of copper and iron, was calculated.

The calculations were performed using the following parameters:

- the model fissile material mass – 200 grams;
- the distance from the neutron generator to the model – 5 meters;
- scintillator with dimensions of 100×100×20 cm was used as a detector and was arranged at the distance of 2 meters from the model;
- neutron yield per pulse – $Y = 10^9$.

The signal value calculation results are given in Table 1 in energetic units. The first column presents the values of signals from the generator without radiation shielding. In the second column the values of signals detected when 4-cm thick moderator (polyethylene) was mounted around the neutron generator are given. The last column presents the values of the model response. Increase of γ-radiation signal (second column) is determined by increase of the radiation capture reaction cross-section (*Fe(n,γ)*) due to the neutron moderation in polyethylene. Here the neutron signal decreases insufficiently. Further increasing of the moderator thickness up to 8 cm results in sharp reduction of the neutron signal and not great decrease of the γ-radiation signal level (the third column in Table). When a radiation shielding in the form of 16-cm thick moderator plus 16-cm thick lead is mounted around the neutron generator the background signal value (the forth column in the Table) becomes smaller than the model response signal value (the last column in Table).

Response type	Thickness of Moderator, cm				Model response
	h_n=0	h_n=4	h_n=8	h_n=16 + h_{Pb}=16	
[MeV]Neutron response	3.2e4	2.9e3	241	1.5	12
[MeV]Gamma-response	2.3e4	3.78e4	9e3	1.16	12.65

Complete suppression of gamma-background is impossible because of the necessity to leave the channel, meant for protons to drift towards the target, open, whereas the neutron output from the target forward can be effectively collimated.

To solve the problem of the forward neutron flow collimation one must study carefully the neutron flow transformation in space. So careful studying is necessary to achieve optimum between the neutron flow density and the irradiated area size, because the additional area irradiated by a neutron flow in the region of the object position is an additional background source.

The obtained values of γ-radiation background enabled to determine minimal and maximal distances for remote detection (see Fig.2.). Minimal distances are determined by the necessity to separate the γ-radiation response in time from scattering neutrons and fission neutrons. Maximum distances are correlated as signal/background ratio.

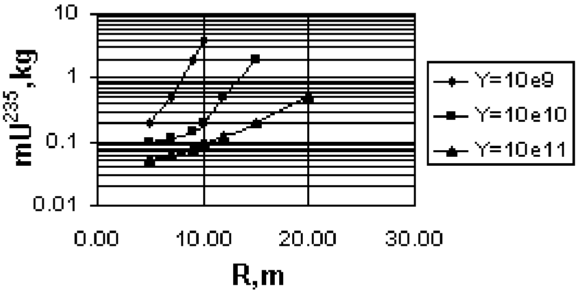

Fig.2. Calculations of limit detection distances dependence on neutron output per pulse (Y), and ^{235}U mass (m)

4. SUMMARY

The conception for the neutron generator radiation shielding presented in this paper has been designed for specific geometry of the experiment on fissile material detection simulating a stationary detecting complex. In our case there are no strict limitations as for the complex overall dimensions and weight that are generally determined by the generator and radiation shielding structure.

When the detecting complex on a mobile platform is designed the probing neutron source and the response signal detector should be placed close to one another. But, if even being so, merely increase of the moderator or absorber thickness cannot solve the problem of the radiation background suppression because of limitations as to the complex overall dimensions and weight. Some other ways to solve the problem of the radiation background suppression are required for this case. For instance, to use the proton accelerator units as shielding – with water and oil in the forming line as a moderator, and the metallic components in combination with boron, cadmium, and lead as an absorber.

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РАЗРАБОТКА НИЗКОФОНОВОГО ИМПУЛЬСНОГО ГЕНЕРАТОРА НЕЙТРОНОВ ПРОМЕЖУТОЧНЫХ ЭНЕРГИЙ ДЛЯ ДИСТАНЦИОННОГО ОБНАРУЖЕНИЯ ДЕЛЯЩИХСЯ МАТЕРИАЛОВ

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В данной статье представлено описание конструкции радиационной защиты для низкофонового импульсного генератора промежуточных энергий, разработанного на основе компьютерных вычислений и данных модельных экспериментов, а также приведены предельные параметры дистанционного обнаружения делящихся материалов с использованием этого генератора. Конструкция магнитно-изолированного диода и геометрия радиационной защиты были оптимизированы в соответствии с проведенными вычислениями.

РОЗРОБКА НИЗЬКОФОНОВОГО ІМПУЛЬСНОГО ГЕНЕРАТОРА НЕЙТРОНІВ ПРОМІЖНИХ ЕНЕРГІЙ ДЛЯ ДИСТАНЦІЙНОГО ВИЯВЛЕННЯ ПОДІЛЬЧИХ МАТЕРІАЛІВ

В. Чорний, Г. Цепілов, О. Фролов, А. Чорний, В. Дубіна, В. Соловйов

У даній роботі представлено конструкцію радіаційного захисту для низькофонового імпульсного генератора проміжних енергій, розробленого на основі комп'ютерних розрахунків і даних модельних експериментів, а також приведені граничні параметри дистанційного виявлення подільчих матеріалів за допомогою цього генератора. Конструкція магнітно-ізольованого діода і геометрія радіаційного захисту були оптимізовані відповідно до проведених обчислень.