TECHNOLOGY FOR FISSIONABLE MATERIALS DETECTION BY USE 100 MEV VARIABLE LINAC *

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Abstract

The technology for detection of hidden fissionable material by use pulse γ-quantum flux generated by high energy (up to 100 MeV) electron linac is discussed. The technology is based on delayed neutron detection. The results of the calculation of neutron yield from the shelter model with hidden ^{235}U inside are presented for concept background. The simulation of electromagnetic interaction with matter was performed by use GEANT. The diffusion approach was developed for description of neutron production and penetration. Calculations were made for one-dimensional model with three-zone composition of ^{235}U and ^{56}Fe. Space-time distribution of neutron fluxes inside shelter, which is irradiated by external γ-source, are presented.

INTRODUCTION

Potentially, one of the most devastating terrorist devices is a weapon that uses nuclear explosives. One possible scenario for the importation of such a weapon is by sea in marine containers. Unfortunately existing automated equipment has low accuracy for illicit fissionable materials (FM) identification. The new method for heavily hidden FM detection by measurement of delayed neutron yield was proposed [1]. This article presents the results of the theoretical calculations for concept background.

CONCEPT DESCRIPTION

It was proposed to detect FM, which are heavily hidden inside marine container, by interrogation inner space with high energy (up to 100 MeV) electron linac. It was also proposed to use existing X-ray machines as the first inspection step. And to use high energy linac for interrogation primary selected suspicious places only [2].

The general scheme for interrogation process looks as the following. High energy electron beam passes the converter and creates high energy gamma. These gamma produce prompt neutron yield after interaction with ordinary materials. And they produce both prompt and delayed neutrons after FM irradiation. Typical interval between prompt and delayed neutron "spikes" has seconds order value.

This shift gives possibility to detect FM with high accuracy. The experiments for detection of trace amount of FM in framework of Chernobil' clean-up program showed high accuracy of proposed approach. Below calculations confirm that the same methodology could be extended for detection of heavily hidden FM.

It is planned that electron linac with the following parameters would be used for experimental proof of the concept: the average current is 1 mA, the electron energy could be varied from 20 to 100 MeV and the frequency of the pulses is up to 300 Hz. Ta target is used as the (e,γ)-converter.

THE CALCULATION FORMALISM

The study of the space-time evolution of the neutron flux in the shelter model, which is irradiated by external γ-source, is carried out in the framework of diffusion approach that has been developed [3-4]. In the one-group approximation the non-stationary diffusion equation for the neutron flux Φ can be written as

$$\frac{1}{v}\frac{\partial\Phi}{\partial t}-\frac{\partial}{\partial x}(D\frac{\partial\Phi}{\partial x})+\Sigma_a\Phi-(1-\overline{\beta})(\nu_f\Sigma_f)\Phi$$

$$=\sum_l\sum_i\lambda_l^iC_l^i+Q\ , \qquad (1)$$

$$\overline{\beta}=\sum_l\beta_l(\nu_f\Sigma_f)_l/\nu_f\Sigma_f\ , \qquad (2)$$

where $\Phi(x,t)$ is the scalar neutron flux, $\Sigma_\alpha(x)=\Sigma_j\sigma_\alpha^jN_j(x)$ is the macroscopic cross section of the neutron reaction of the α-type, (the index α corresponds to the reactions of neutron absorption (a) and fission (f)), $N_j(x)$ is the concentration of j'th nuclide at the point x; σ_α^j is the corresponding effective one-group microscopic cross section of the j'th nuclide; $\nu_f\Sigma_f=\Sigma_j\nu_f^j\sigma_f^jN_j(x)$, ν_f^j is the mean number of neutrons produced at the single nuclear fission event for the j'th fissile nuclide; $\overline{\beta}$ is the effective fraction of delayed neutrons, $\beta_j=\Sigma_i\beta_j^i$, here β_j^i, C_j^i and λ_j^i are the portion of delayed neutrons, the concentration and decay constant of the precursor nuclei in the i'th group of the j'th fissile nuclide, correspondingly; $D(x)=1/(3\Sigma_{tr}(x))$ is the diffusion coefficient, $\Sigma_{tr}(x))$ is the macroscopic transport cross-section, v is the one-group neutron velocity.

We assume that the left boundary of the system is subjected to an external photon flux Φ_γ coming from a γ-source of certain intensity. The simulation of electromagnetic interaction with matter was performed by use GEANT. The corresponding rate of neutron generation in each point of the composition due to the (γ,n) and (γ,f) reactions with nuclei involved in the assembly composition is defined by

$$Q(x)=\int_{E^{th}_{(\gamma,n)}}^{E_\gamma^{\max}}\Sigma_{(\gamma,n)}\Phi_\gamma dE_\gamma+\int_{E^{th}_{(\gamma,f)}}^{E_\gamma^{\max}}\nu_{(\gamma,f)}\Sigma_{(\gamma,f)}\Phi_\gamma dE_\gamma\ , \quad (3)$$

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The equations of nuclear kinetics for 6 groups of the precursor nuclei of delayed neutrons take the form

$$\frac{\partial C_l^i}{\partial t} = -\lambda_l^i C_l^i + \beta_l^i (\nu_f \Sigma_f)_l \Phi \qquad (4)$$

The following symbols are used in above equations (3) and (4):

$$\Sigma_{(\gamma,n)}(x,E_\gamma) = \sum_j \sigma^j_{(\gamma,n)}(E_\gamma) N^j(x)$$

$$\nu_{(\gamma,f)}(E_\gamma)\Sigma_{(\gamma,f)}(x,E_\gamma) = = \sum_j \nu^j_{(\gamma,f)}(E_\gamma)\sigma^j_{(\gamma,f)}(E_\gamma)N^j(x),$$

where $\Sigma_{(\gamma,n)}(x,E_\gamma)$ ($\Sigma_{(\gamma,f)}(x,E_\gamma)$) is the macroscopic cross section of the (γ,n) (photo fission (γ,f)) reaction, $\sigma^j_{(\gamma,n)}(E_\gamma)$ ($\sigma^j_{(\gamma,f)}(E_\gamma)$) is the total microscopic cross section of the (γ,n) ((γ,f)) reaction with nuclei of the *j*'th nuclide, $\nu^j_{(\gamma,f)}(E_\gamma)$ is the mean number of neutrons, which are produced at the single photo fission event for the *j*'th fissile nuclide; $\Phi_\gamma(E_\gamma)$ is the photon flux with energy E_γ, $E^{th}_{(\gamma,n)}$ ($E^{th}_{(\gamma,f)}$) is threshold energy for the corresponding (γ,n) ((γ,f)) reaction, E_γ^{max} is the energetic top boundary of the gamma-radiation.

In the case under consideration the neutron flux Φ weakly varies during the characteristic decay time of the precursor nuclei that emit delayed neutrons. Therefore, number of the kinetic equations (4) can be reduced. The complete statement of the problem considered includes the set of partial differential equations (1), (4) and corresponding initial and boundary conditions to them as well.

For solving this non-stationary problem we have used the finite-difference method. For calculations of the effective one-group microscopic cross sections we used the group neutron fluxes Φ^g (*g* is the number of neutron energy group) for the initial assembly calculated from solving the stationary multigroup problem. Calculations were performed in the 26-group approximation using the library of group neutron constants from Ref. [5].

CALCULATION RESULTS

We consider a model of the shelter as three layers composition which consists of two layers of ^{56}Fe (thickness of each layer is 10 in) with high-enriched (100%) ^{235}U between them (uranium layer thickness is 13 mm, its porosity is 0.8). The composition width, $0 \le x \le L$, is divided into $M = 200$ intervals of the spatial calculation mesh.

Fig. 1 presents the spatial distribution of density neutron generation rate $Q(x)$ (3) inside shelter model that is calculated for the electron beam energy 100 MeV. In the first and third zones the curve of $Q(x)$ exponential decreases that corresponds to the photon flux damping when the γ-radiation pass the iron. In the second zone the noticeable enhancement of $Q(x)$ value is observed. This burst of the neutron generation rate is mainly connected with the contribution of (γ,*f*) reaction on ^{235}U. It also should be noted that average number of neutrons produced at the single fission event of ^{235}U nuclide is greater than two and has the tendency to increase with the photon energy growth. Besides, the cross section values of the (γ,*n*) reaction with ^{235}U is greater than the corresponding values for ^{56}Fe in the giant dipole resonance region.

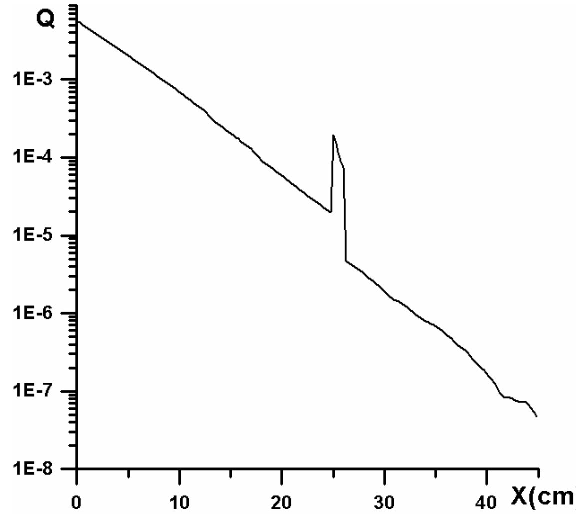

Figure 1: Spatial distribution of Q(x) [$\times 10^{16}$ $cm^{-3}s^{-1}$] inside the shelter model.

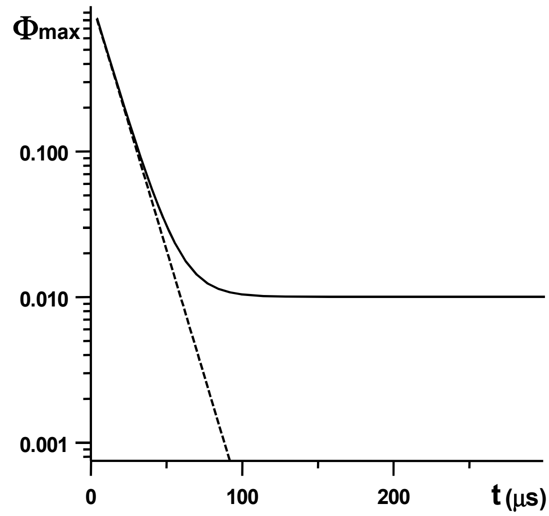

Figure 2: Time dependence of Φ_{max} directly after the moment of switching off the photon flux at $t_{off} = 1$ sec.

The calculations of non-stationary neutron flux inside shelter model also were conducted. They show that the maximum value of the neutron flux Φ_{max} in non-stationary conditions reaches only 80 % of Φ_{max} value for the corresponding stationary solution. The shape of neutron flux distribution at the time t_2 (switching off the photon flux) has the same shape as for the t_3 (1 sec later). However, at t_3 the Φ_{max} becomes of about two orders lower than its value at t_2.

The similar picture is observed for the time dependence of the neutron leakage current $j_L = D\partial\Phi/\partial x$ from the right boundary of the composition. The maximum j_L value is 3 10^{14} $cm^{-2}s^{-1}$. j_L reaches this value at the moment of switching off the photon flux ($t_{off} = 1$ sec). Just after switching off the external γ - source, the j_L rapidly falls down. Then j_L changes very slowly during one second and takes on the magnitude of 3.4 10^{12} $cm^{-2}s^{-1}$ at the moment $t = 2$ sec. Transition period for Φ_{max} is shown on fig. 2 (continuous line). Dotted line is the results of calculations without delayed neutron production.

Note that the energy production density reaches the maximum value of about 17 kW*cm $^{-3}$ in ^{235}U layer at the moment of switching off the external photon flux. The energy production density decreases rapidly after switching off the photon flux and takes the value near of 0.2 kW*cm $^{-3}$.

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CONCLUSIONS

5.1. Present calculations showed that electron linac parameters (see chapter 2) provides delayed neutron flux on 10^{12} $cm^{-2}s^{-1}$ level for considered shelter configuration. This value provides reliable registration of hidden FM even by use standard helium detectors with neutron moderator and efficiency on 70% level.

5.2. Available Ukrainian electron variable linac is the fastest and the most inexpensive facility for experimental proof of proposed concept.

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