Photo-activation method for electron energy determination of linear accelerator

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Гамма-активационный метод измерения энергии пучка электронов на линейном ускорителе.

Неизвестная энергия пучка построенного линейного ускорителя электронов LINAC-200 оценивалась путем фотоактивации только одного детектора-фольги из естественного индия. Измерялись выходы изотопов R в результате четырёх фотоядерных реакций: ^{115}In(γ, γ')^{115m}In, ^{115}In(γ, n)^{114m}In, ^{115}In(γ, 2n)^{113m}In и ^{113}In(γ, 2n)^{111}In . Соотношения активностей в насыщении R (^{113m}In)/ R (^{115m}In), R(^{114m}In)/ R (^{115m}In) и R(^{111}In)/ R (^{115m}In) в зависимости от энергии электронов (10 – 23 МэВ) определяли с помощью гамма-спектроскопии индиевых фольг, предварительно экспонированных в тормозном излучении микротрона МТ-25 ЛЯР ОИЯИ. Выбор циклического ускорителя МТ-25 в качестве эталонного был сделан в связи с тем, что энергия ускоренных на нем электронов известна с точностью не хуже 1%. После экспозиции индиевых детекторов в пучке тормозного излучения линейного ускорителя LINAC-200 так же находили соотношения активностей насыщения образовавшихся изотопов. Учитывая, что оба облучения на микротоне МТ-25 и ускорителе LINAC-200 были выполнены в одинаковой геометрии с использованием одной и той же тормозной мишени (3 мм вольфрама), была оценена неизвестная энергия ускоренных электронов путем сравнения измеренных соотношений активностей изотопов индия. При расчете активностей в насыщении были приняты во внимание небольшие различия в колебаниях во времени токов пучков..

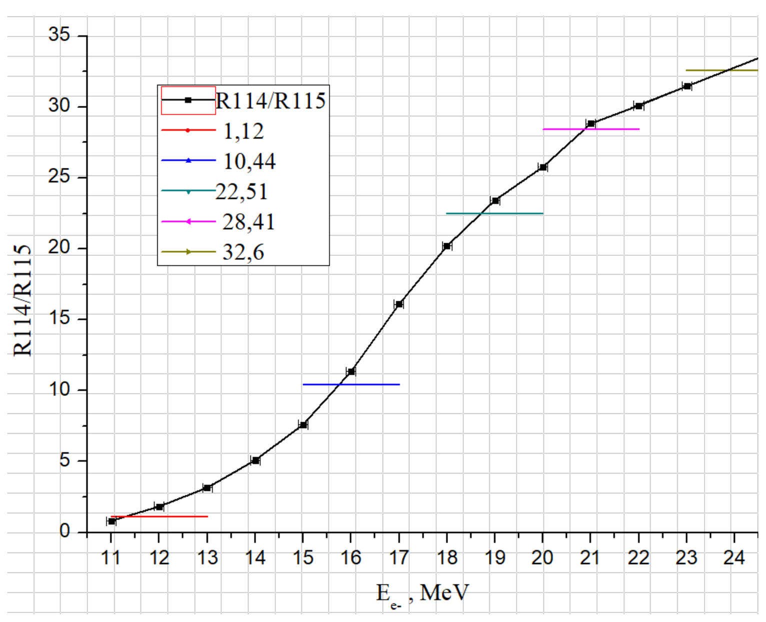
Unknown energy of electron beam of linear accelerator LINAC-200 was estimated by photo activation of only one activation detector – foil of natural indium. Four different photonuclear reactions were considered: ^{115}In(γ, γ')^{115m}In, ^{115}In(γ, n)^{114m}In , ^{115}In(γ, 2n)^{113m}In and ^{113}In(γ, 2n)^{111}In. Ratio of saturation activities R(^{113m}In)/R(^{115m}In), R(^{114m}In)/R(^{115m}In) and R(^{111}In)/ R (^{115m}In) were determined by standard gamma spectroscopy in electron energy region of interest (10 MeV – 23 MeV) using indium foils exposed in the FLNR microton MT25 bremsstrahlung beam. The choice of cyclic accelerator MT25, as a reference machine, was made due to the fact, that the energy of its electrons is known with an accuracy not worse than 1%. Same ratios of saturation activities were determined after exposition of In activation detectors in photon beam of linear accelerator. The fact that both irradiations, by microton MT25 and accelerator LINAC-200 , were performed in identical geometry using same target (3 mm of Tungsten) allowed us to estimate electron energy of accelerator by comparison of ratios of saturation activities obtained by both machines. Small variation in accelerator electron current was taken in consideration.

View the linear accelerator LINAC 200

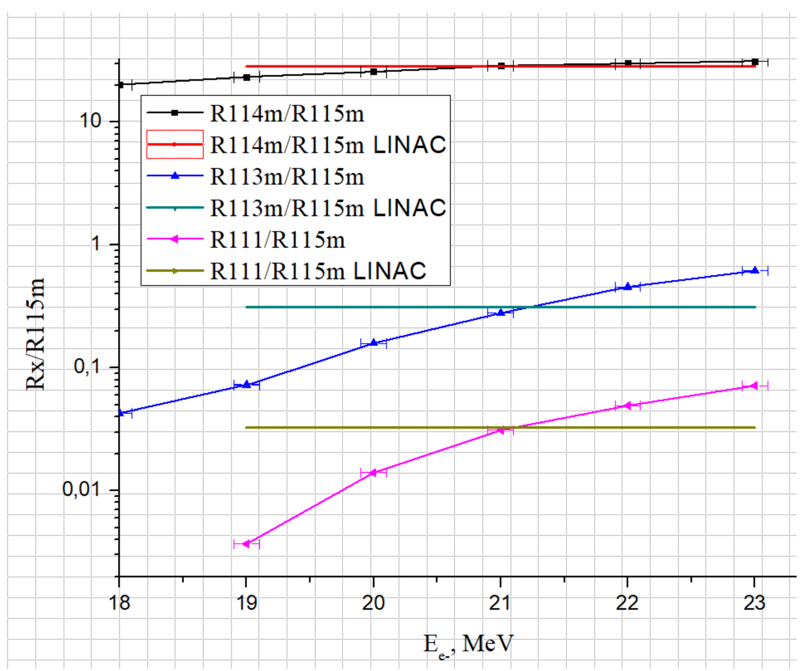
View the microtron MT-25

Basic parameters of the microtron MT-25

Max. energy of electrons, *[MeV]*	**23.5**
Average current, *[μA]*	**20**
Pulse frequency, *[Hz]*	**50÷800**
Pulse length, *[μs]*	**2÷3**
Power consumption, *[kW]*	**20**



Dependence of the ratio of the activity of indium isotopes ^{114}In/^{115}In on the energy of electrons accelerated on a microtron. (the lines show the ratio of the activity of indium isotopes measured on LINAC and the corresponding energy value)



Energy of 21±0,1 MeV measured on LINAC by the ratio of different isotopes of indium.

Materials and methods

The yield of products of some nuclear reactions can be described by the saturation activity R:

$$R = \int \sigma(E) \cdot \Phi(E) \cdot dE, \qquad (1)$$

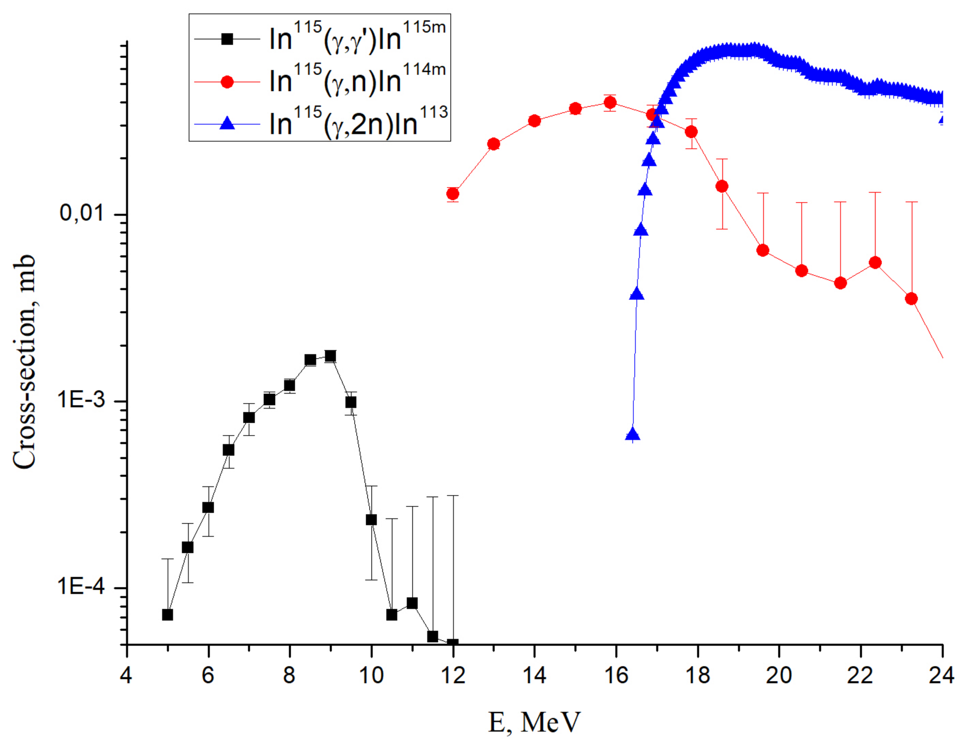
where $\sigma(E)$ is cross section for observed nuclear reaction, $\Phi(E)$ is flux of photons.

Table 1

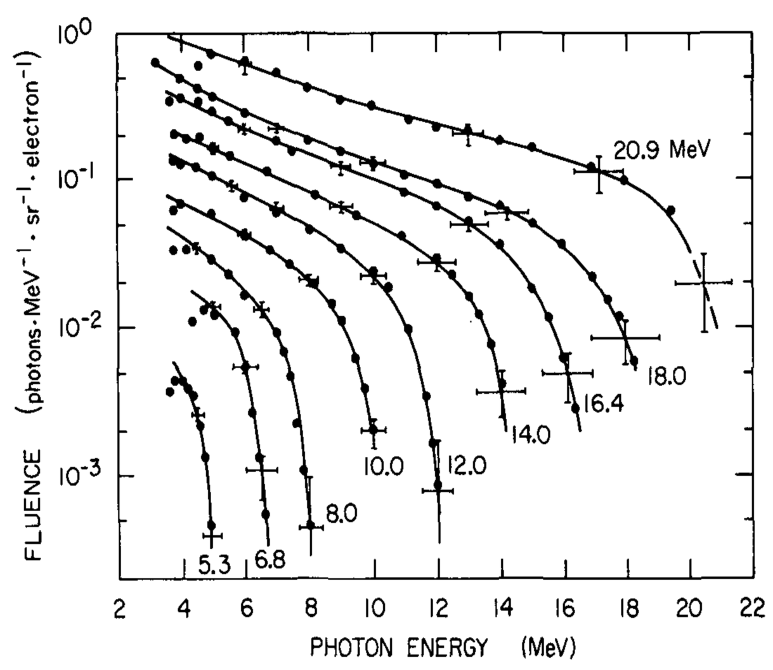
Data relevant to the nuclear reactions being monitored

In last column absolute photon intensities (quantum yields) are given in parenthesis.

	$T1/2$ of reaction product	$E\gamma$ [keV] ($p\gamma$)
115In (γ, γ')115mIn	4.486 h	336.26 (0.458)
115In (γ,n) 114mIn	49,51 d	190.29 (0.156)
115In (γ,2n) 113mIn	1.658 h	391.69 (0.642)
113In (γ,2n) 111In	2.81 d	1,3 (0.9), 245,4(0,94)



The cross sections σ (E) of the reaction 115In(γ, γ')115mIn 115In(γ, n)114mIn and 115In(γ, 2n)113In,

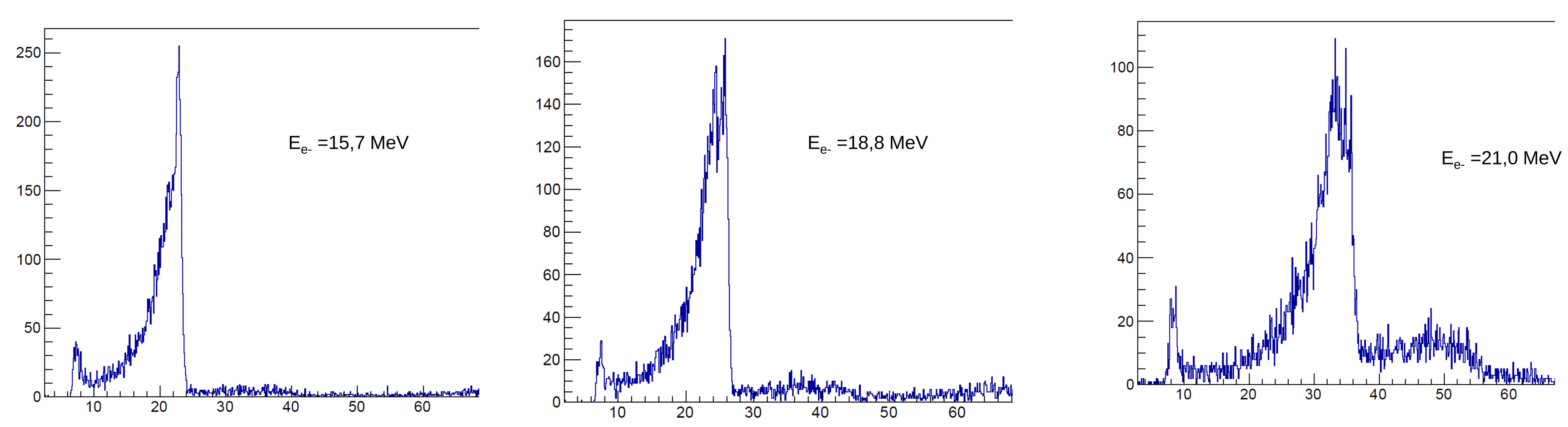


Bremsstrahlung spectra at 0 degree from intermediate-thickness targets of high – Z material.
A.A. O'DELL, JR. et al. NIM 61 (1968) 340-346;

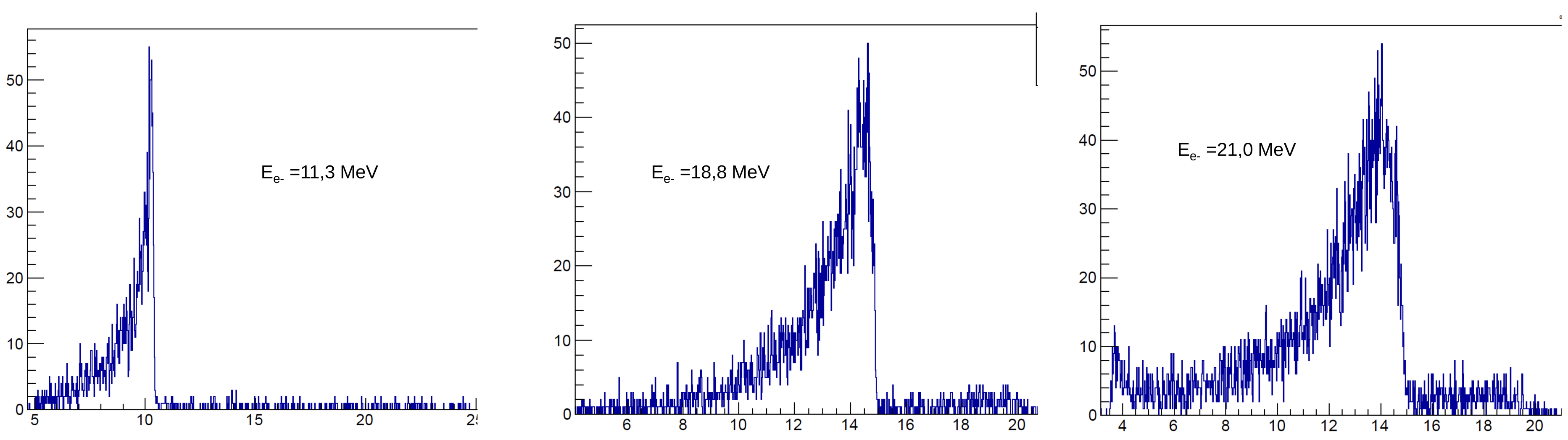
Due to the difference in the energy dependences of the cross sections the increase of saturation activities of photoactivation vary in an unequal manner with the change of the energy of the bremsstrahlung beam.
The saturation activity can be determinate by measuring the gamma spectra emitted by the product of nuclear reaction. The intensity of a single gamma line in recorded spectra can give numerical value of saturation activity as:

$$R = N\gamma\lambda M/(mNAv\varepsilon\eta p\gamma\, e^{-\lambda\Delta t}(1 - e^{-\lambda tirr})(1 - e^{-\lambda tm})) \qquad (2)$$

where $N\gamma$ is the number of detected gamma photons of chosen energy, λ is the decay constant, M and m are the mass number and the mass of the activation detector used, NAv is Avogadro number, ε is the efficiency of the detector at the chosen energy, η is the natural abundance of activated isotope, $p\gamma$ is the quantum yield of detected photons, Δt, $tirr$ and tm are cooling, irradiation and measurement time respectively.



Single-electron spectra measured by scintillation detector BGO on LINAC



Single-electron spectra measured by scintillation detector LaBr on LINAC

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