Computing Investigations of the Neutron Producing Target for Electron Accelerator

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Abstract. Using FLUKA code the investigations of neutron yields under irradiation of tungsten and some other targets by the accelerated electrons were carried out. An influence of beryllium around the target on integral neutron intensity was also considered. The obtained results show that the neutron yield augmentation stops at 30 – 50 MeV electron energy if a thickness of W-target is more than 4 cm. The located around the target beryllium block can give an increase of neutron yield from 5% up to 40%, when electron energy is reduced from 50 MeV to 20 MeV. The results for W target are compared with EKON-experiment data obtained earlier at IBR-30 booster. Neutron yields comparison for different target materials was also presented. Usage of U-238 or combined W-Pu targets is proposed for consideration as an alternative to application of second section of linac at IREN-neutron source.

1. Introduction

Difficulties with achievement of designed parameters of the first section of electron accelerator at IREN facility and comprehension that the neutron intensity of IREN can only redouble by connection of the second section attracted our attention to investigations of neutron- producing target characteristics. We examined how the target qualities depend on its sizes, material or energy of electron beam. The purpose of our calculations was to evaluate possibilities for essential augmentation of IREN intensity without the second acceleration section using. In the work [1] the potentialities of 20% growing the neutron intensity due to ^{9}Be(n,2n)2^{4}He reaction is shown by W target immersion in beryllium block. Furthermore, an application of beryllium in neutron- producing targets or at shaping the spectra beams for neutron radio-therapy was discussed in [2,3].

All the calculations in the present work were carried out using the FLUKA code [4]. The obtained neutron yields for naked tungsten target are compared with the results calculated for other heavy targets. The estimations of neutron yields were carried out for W target with taking into account an addition generation of neutrons in Be owing to ^{9}Be(γ,n)2^{4}He reaction, which threshold is ~1.6 MeV only. The accelerated electrons passing through the beryllium was also analyzed. The calculated neutron yields for the tungsten target and theirs changes due to electron beam attenuation by the beryllium scatterer before the target are compared with the results obtained from testing the different W-targets within the bounds of EKON program at the IBR-30 booster in 1995 – 2001 [5].

The following results were obtained:

- the neutron yields after irradiation of tungsten and another materials by accelerated electrons in dependence of target sizes, electron energy and electron beam profile;
- the neutron yields for different configurations of tungsten target with respect to beryllium surroundings;

- electron spectra after mono energetic electrons passing through Be, Fe and H_2O of different thicknesses;
- evaluation of weakening the neutron yield for different materials located before tungsten target in IREN facility.

2. Neutron yields from tungsten and other heavy targets

In Tables 1 and 2 the calculated conversion coefficients (n/e) obtained for different thicknesses and diameters of tungsten target for various electron energies are presented. It is evident that growing the neutron yield stops with increasing the target thickness or its diameter with respect to the neutron beam sizes. This result is in a good agreement with conclusions of [6].

Table 1. Neutron yield Y(n/e) × 10^{-3} for W-target

Target length L, cm	0.1	1	2	3	4	5	6
E_e=30 MeV	0.227	5.16	7.04	7.42	7.49	7.55	7.58
E_e=50 MeV	–	–	14.5	–	16.3	–	16.6

Table 2. Neutron yield Y(n/e) × 10^{-3} for W-target (L=4 cm)

Target diameter, cm	0.5 e^--beam $0.15\times0.15 cm^2$	1 e^--beam $0.3\times0.3 cm^2$	2 e^--beam $0.3\times0.3 cm^2$	4 e^--beam $0.3\times0.3 cm^2$	6 e^--beam $0.3\times0.3 cm^2$
E_e=20 MeV	1.76	–	–	–	–
E_e=25 MeV	3.25	–	–	–	–
E_e=30 MeV	4.71	6.33	7.59	8.14	8.19
E_e=50 MeV	10.4	13.8	16.4	17.4	17.6

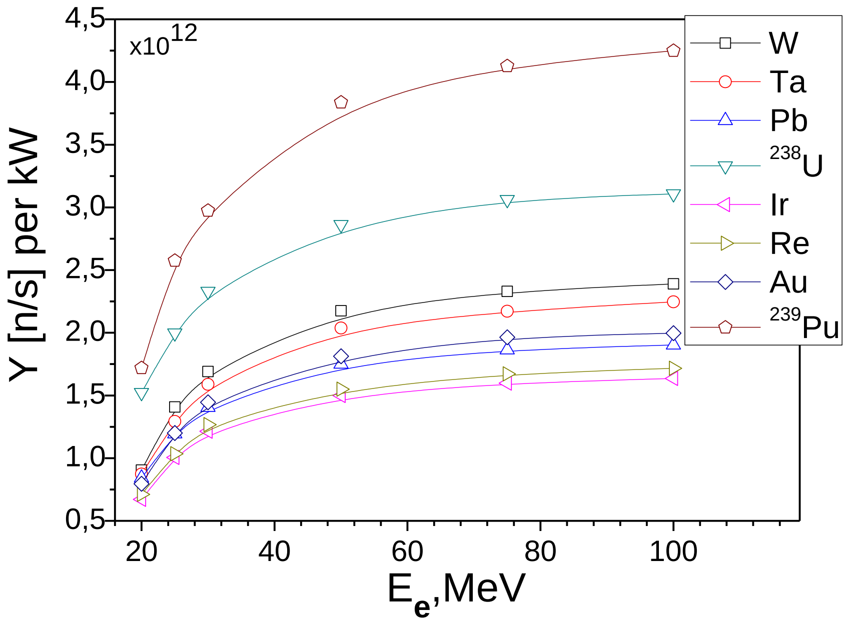


Fig.1. Calculations of the neutron yields (per 1 kW of beam power per second) depending on electron energy for different heavy targets

In Table 3 the results of neutron yields calculations depending on electron energy for different target materials are shown (per 1 kW of electron beam power per second), and they are compared to some known calculated and experimental data. The results of our calculations are also shown in Fig.1.

Table 3. Neutron yield per 1 kW electron beam power in 10^{12} n/s

	Electron energy, MeV						
Target	**20**	**25**	**30**	**36**	**50**	**75**	**100**
W	0.905 *0.470*	1.41 *0.832*	1.69 *1.06*	1.78 *IBR-30* *1.8 – 2.2*	2.17 *1.36* *~2.1*	2.33	2.39 *1.28*$^{*)}$ *~2.2*$^{**)}$ *1.7*$^{***)}$ *Khark 1.9*
Ta	0.874 *0.425*	1.29 *0.696*	1.59 *0.877*		2.04 *1.15* *~1.7*	2.17	2.25 *1.13*$^{*)}$ *~1.9*$^{**)}$ *1.3*$^{***)}$ *ORELA 2.0*
Pb	0.842 *0.660*	1.20 *1.03*	1.41 *1.27*		1.75 *1.62* *~1.6* *1.6–1.7*$^{+)}$	1.86	1.90 *1.53*$^{*)}$ *~1.7*$^{**)}$ *1.6–3.2*$^{***)}$
U	1.52 *1.25*	2.00 *1.92*	2.33 *2.37*		2.86 *3.01* *~3.1* *3.4*$^{+)}$	3.06	3.11 *2.89*$^{*)}$ *~3.3*$^{**)}$ *3.9*$^{***)}$ *Khark 3.3*
Ir	0.671	1.01	1.21		1.50	1.60	1.63
Re	0.711	1.04	1.27		1.55	1.67	1.72
Au	0.796	1.20	1.45		1.81	1.96	2.00 *1.8*$^{***)}$
Th	1.38	1.89	2.20		2.74	2.89	2.94
Pu	2.38	2.60	2.97		3.84	4.13	4.25

$^{*)}$ cursive lines – calculation results from [6]; $^{**)}$ values from [7]; $^{***)}$ values from [8]; $^{+)}$ values from [9]; *IBR-30* [5]; *ORELA* [10]; *Khark* [11]

In Fig.2 the results for Pb, W and U-238 are compared to values from data bank [7]. It is possible to note their agreement within the bounds of a few percent. Results from Table 3 and Figs. 1 and 2 demonstrate that heavy targets with highest density (like Ir, Re or Au) cannot secure a conversion coefficient more than W have. In case of W target the calculations for electron energies 200 and 300 MeV, which are higher than pion- producing threshold, were also made. These results confirm a conservation of the plateau in dependence on neutron yield Y(E) per 1 kW beam power.

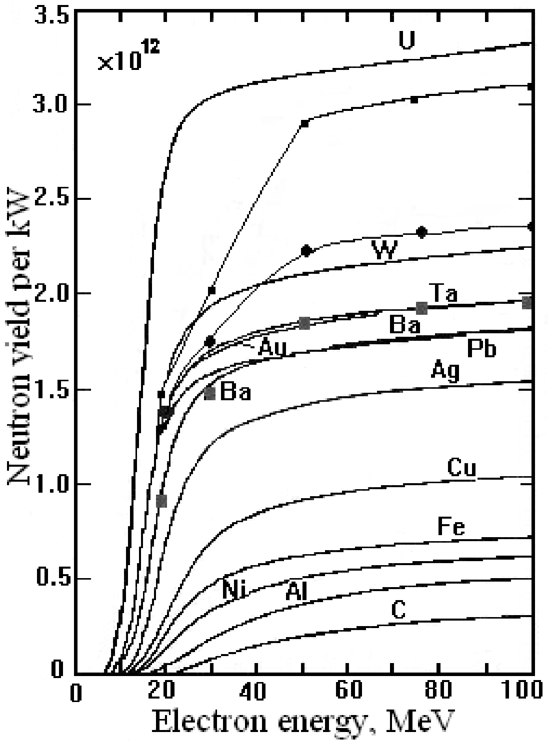


Fig.2. Comparison of results obtained using FLUKA code for Pb, W and U-238 (points) with the data from [7]

3. Some parameters of W-Be target

The effect of tungsten target submergence into beryllium block (with a diameter of 15 cm and a height of 10 cm) at a depth h was considered. Calculations were made for configuration, which is shown in Fig.3. The target had a diameter of 4 cm, and its thickness was varied.

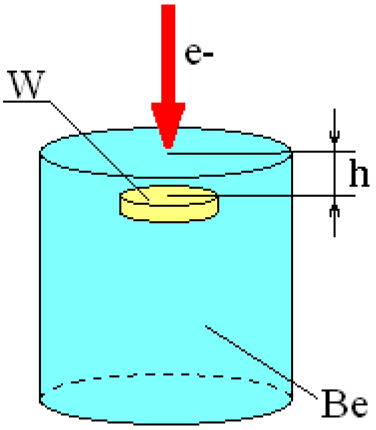


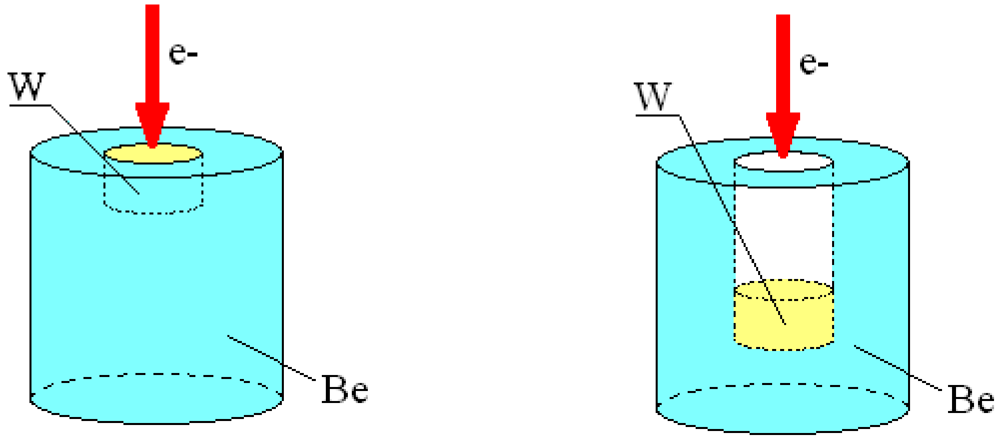
Fig.3. Scheme of W-target disposition in beryllium block

In Table 4 neutron yields are presented in comparison with yield from the naked tungsten target. As you can see, if thin tungsten target are immersed into the beginning of the beryllium block, an essential rise of neutron yield is obtained. However, the yield falls considerably, when a thickness of W-target and depth of its submergence into beryllium block increase. The observed effect can be explained by significant self-absorption of the bremsstrahlung low energy part. The influence of beryllium around the tungsten target was considered in configurations, which are shown in Figs. 4a and 4b.

Table 4. Neutron yields Y(n/e) × 10^{-3} for different W thickness and W-Be configurations

W- thickness, cm	0.25	0.5	1.0	4.0
naked W- target	1.19	2.95	5.37	8.18
W in Be, h=0.1 cm	2.72	4.46	6.16	8.18
W in Be, h=5 cm	0.93	1.16	1.43	1.86

The calculations demonstrate that if tungsten target with thickness of 4 cm immerses into beryllium block in these two variants, neutron yield can rise with regard to the naked target from 10 to 40%. At the same time, the effect of beryllium becomes more noticeable with decreasing the target diameter and electron energy. That is explained by relative rise in portion of soft gamma- quanta at decreasing the target size and electron energy. Unfortunately, at the electron beam energy more than 30 MeV the beryllium surroundings doesn't provide increasing a neutron yield in comparison with the naked tungsten target.



a **b**

Fig.4. Configurations of W-Be target

4. Electron beam passing through beryllium. Comparison of calculations by FLUKA code with the experimental EKON results obtained for IBR-30 booster

The FLUKA code allows to investigate an electron beam passing through different materials and, thereby, to evaluate an influence of these materials, which are located before the target, for the neutron yields. In Fig.5 the arrangement of the IREN bremsstrahlung target is schematically shown. In Fig.6 a spectrum of monoenergetic neutrons with E_e=30 MeV after their passing 1.5 mm of stainless steel and 10 mm of water is presented.

The direct calculations taking into account mentioned materials show that neutron yield decreases at 16%. And at the electron beam energy $E_e = 25$ MeV the neutron yield weakening would be 27%.

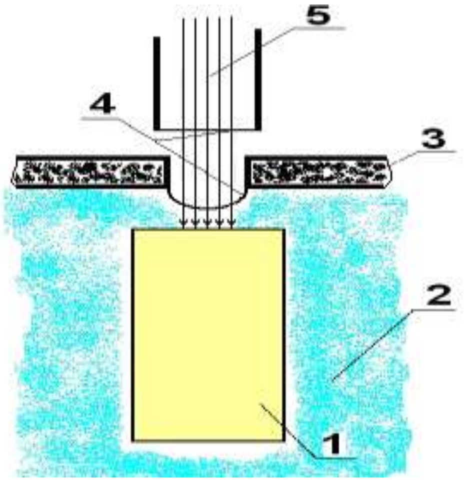


Fig.4. Scheme of the IREN neutron generating target: 1 – tungsten, 2 – freezing water, 3 – container cover, 4 – stainless steel membranes, 5 – electron beam

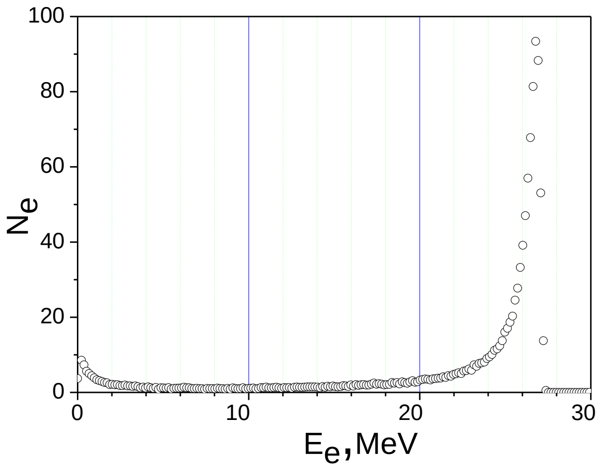


Fig.5. Spectrum of monoenergetic electrons with the energy $E_e = 30$ MeV after passing through 1.5 mm of stainless still and 10 mm of water

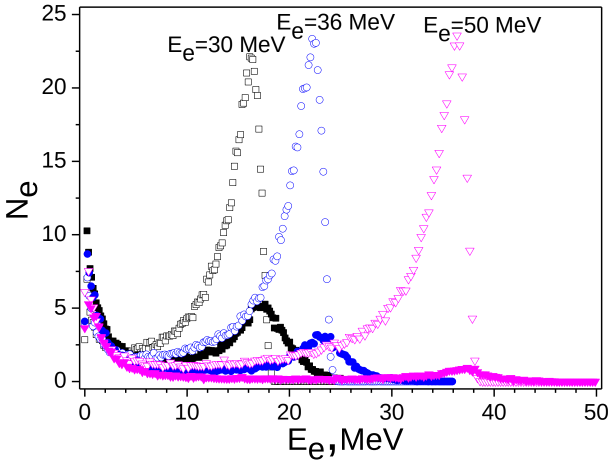


Fig.6. Spectra of electrons with initial energies 30, 36 and 50 MeV after passing through 5 cm of beryllium. Open points are electron spectra at the bottom end of beryllium cylinder, black points are the spectra of electrons from the side face of Be cylinder

In Fig.7 the spectra of electrons with different initial energy after passing through 5 cm of beryllium are presented.

We computed electrons passing through beryllium, beryllium effect on the neutron yield (when beryllium located before the tungsten target) and compared our calculations with the results of experimental investigations at the IBR-30 booster from [5]. In these experiments the electron beam with the energy 36 MeV run through beryllium block with a thickness of 5 cm situated before the tungsten target. For several variants of W targets the beryllium block influence on conversion coefficient and on temperature regime (with the purpose to make better a cooling of the target and Pu core) were tested.

The experimental results of [5] demonstrated that using beryllium reduces essentially a thermal load in the most dangerous points of IBR-30 construction, and at the same time the conversion coefficient was decreased at ~30% only. The obtained evaluations showed that tungsten target scattered about 50% of electron beam power into the reactor core. The author's conclusion was that ~ 47% of conversion took place at the material located just in the core of IBR-30. The conversion coefficients obtained in [5] are presented in Table 3 as experimental ones. But in our calculations a reduction of neutron yield out of the tungsten target after electrons passing through 5 cm of beryllium is 3 – 5 times. To understand this contradiction we carried out calculations with the IBR-30 target, which had a diameter of 2 cm and length of ~8 cm, surrounding it with a tungsten or plutonium cylinder. It was made to evaluate the influence of gammas, which occur in bremsstrahlung target and irradiate the neighboring materials, for the total neutron yield.

The estimations showed that W-target immersion in cylinder (of tungsten or of plutonium) with a wall thickness of 2 cm gives a rise of neutron yield due to additional conversion in it. In case of tungsten cylinder the increase was 10−30% (in dependence on electron beam size relatively to the target diameter), and for plutonium cylinder there was 2.4 times rise. At the same time the question remains about beryllium role. As it is follows from the calculations, if 5 cm of beryllium is placed before W-target (see Fig.8) the total neutron yield decrease just 2.4 times.

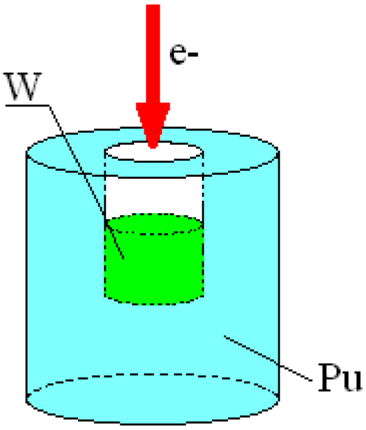


Fig.8. Scheme of the W–Pu target

5. Conclusion

As a result of the realized investigations we can make a summary of them.

- If the energies of the electron beam are less than 25 MeV it is possible to use an additional beryllium converter around of heavy target to raise a neutron yield. Unfortunately, at the electron energy more than 30 MeV an application of Be is not efficiently. However, beryllium moderator can be of interest to some of tasks, in which the neutron spectrum more hard than after water is demanded.
- It is expediently to study a question of using U-238 or Th-232 targets as an alternative to the second section of IREN accelerator.
- It is shown that using of the available Pu-rods is of interest not as a multiplying zone, but as an additional single- or double-layer converter around the tungsten target.

Of course, it will require solving the task of gas-cooling for combined target, but such experience exists in FLNP.

References

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