# OPTIMIZATION OF ELECTRON LINAC OPERATING CONDITIONS FOR PHOTONUCLEAR ISOTOPE PRODUCTION*

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*Abstract*

An efficient isotope production by the photonuclear method can be realized around the electron accelerator with energy of up to 100 MeV at a beam power ≥10 kW. Owing to the interaction with the bremsstrahlung converter, the beam is transformed into a flux of mixed e,X radiation, to which the isotopic target is exposed. In this case, the density of absorbed radiation power in the output devices of the accelerator may range up to $>10^3$ W/cm$^3$, that necessitating a continuous cooling of the devices.

The communication describes the method for optimizing the accelerator regime (electron energy, pulsed current and beam size, pulse repetition rate) and the composition of output devices to provide the maximum yield of isotope product with the maintenance of thermal stability of structural elements. To exemplify, the results of accelerator KUT-30 (45 MeV, 10 kW) optimization at conditions of medical isotope Cu-67 production are reported. Simulation based on a modified PENELOPE/2006 code was employed to compute the Cu-67 generation rate in the Zn target, and also the absorbed radiation power in output device elements for different operating conditions of the accelerator with due regard for its loading characteristic. The simulation results were used to calculate the target and the converter (Ta) temperature at various thicknesses of the latter and at real cooling parameters. Conditions have been established for the maximum Cu-67 yield with keeping thermal stability of the target device.

## INTRODUCTION

The photonuclear method provides the possibility of principle to produce a number of medical isotopes with a sufficient yield at relatively low costs and a low level of radioactive wastes (e.g., see [1-3]). This production can be realized around an electron accelerator with energy up to 100 MeV at a beam power of ≥10 kW. The special feature of the process is the usage of “thick” bremsstrahlung converter and isotopic target operating at high heat load conditions ($>10^3$ W/cm$^3$).

Preliminary investigations have revealed that the water cooling of both the accelerator exit window and the converter (as a set of Ta plates) ensures a reliable operation of the units at a mean beam current value up to 200 µA and a beam size of ≈1 cm [4]. So, the most critical element of the technology, as regards heat stability, is the target.

Let $P_m$ denote the ultimate possible value of absorbed radiation power in the target. This parameter is dependent on the target structure and material, and also on the cooling conditions. Besides, in electron linacs the beam pulse current value $I_{imp}$ (and hence, its mean value I) is related to the electron energy by the so-called load characteristic (LC). The latter is, in its turn, dependent on the pulse high-frequency power (HFP) that comes to the accelerating structure. Thus the optimization of the mode of accelerator operation for photonuclear isotope production corresponds to a search for the maximum of functional

$$A_{\max} = Max\left\{A\left[\Delta_c; E_0, I(HFP, F); P < P_{\mathrm{m}}\right]\right\} \quad , \quad (1)$$

where $A$ is the yield of the desired isotope, $\Delta_c$ is the converter thickness, $E_0$ is the electron energy, F is the beam pulse frequency, P is the absorbed radiation power in the target.

Since it is rather difficult to establish the connection between the parameters of functional (1) in the analytical form, it appears reasonable to resort for its analysis to computer simulation, in particular, to the use of the program system PENELOPE/2006 as the basis [5]. The modification of the system, supplemented with the database on the excitation functions of photonuclear reactions, makes it possible to calculate simultaneously the isotope yield and the absorbed power in the output devices [6].

The communication describes an example of realization of this approach for optimizing the target device structure and the mode o operation of the accelerator KUT-30 created at KIPT for photonuclear production of isotopes [7]. Natural zinc target option for Cu-67 isotope production has been investigated.

## SIMULATION CONDITIONS

The output devices of simplified composition have been considered (Fig.1).

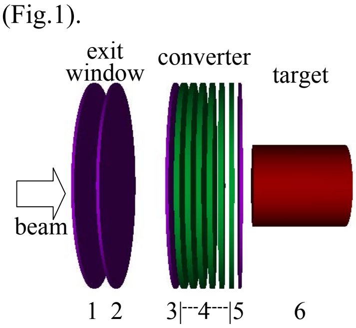


Figure 1: Configuration of KUT-30 output devices.

They include the exit window of the accelerator (0.05 mm thick Ti foils **1**, **2** separated by a 4 mm spacing

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for cooling water), the converter (0.05 mm thick Ti foils **3**, **5**, between which 3 to 6 Ta converter plates **4**, each being 1 mm thick, are placed with 1.5 mm spacings for cooling water), and also the Zn target (2x2 cm cylinder).

It was stipulated in the calculations that the target cooling conditions provide permissible absorbed power $P_m$=500, 800, 1000 and 1400 W. The available operating conditions of the accelerator KUT-30 are as follows: HFP=10, 12 MW; F=50, 100, 150 Hz; $E_0$=30, 35, 40, 45 MeV; the beam pulse length is 3.7 µs.

The LC of the accelerator has the form

$\mathbf{E_0(MeV)= -0.019 \cdot I_{imp}(mA)+45}$ - for HFP=10 MW, (2)

$\mathbf{E_0(MeV)= -0.019 \cdot I_{imp}(mA)+50}$ - for HFP=12 MW. (3)

## SIMULATION RESULTS

The parameter of optimization is the Cu-67 activity produced for 1 hour in the target, *A(mCi/hour)*. Its value is controlled by the number of converter plates and the accelerator operating conditions. The limiting factor is the value of absorbed radiation power in the target P(W).

Tables 1 and 2 give the simulation data for the conditions ($\Delta_c$=4 mm, HFP=10 and 12 MW), and Figs.2 and 3 show the Cu-67 yield and absorbed power in the target for $\Delta_c$=3 and 6 mm. The mode of accelerator operation at HFP=10 MW and frequency of 50 Hz is denoted as HFP10F50. The other modes of operation are identified similarly.

Tables 3 – 6 give the integrated data on optimum operating conditions of KUT-30 to provide the highest yield of Cu-67 in the target.

Table 1: Beam parameters, absorbed power and Cu-67 yield in the Zn target ($\Delta_c$=4 mm, HFP = 10 MW)

| Energy $E_0$, MeV | | 30 | 35 | 40 | 45 |
|---|---|---|---|---|---|
| | $I_{imp}$, mA | 789.5 | 526.3 | 263.2 | - |
| F=50 Hz | I, mkA | 146.1 | 97.4 | 48.7 | - |
| | P, W | 294.4 | 307.1 | 211.9 | - |
| | A, mCi/hour | 1.021 | 1.330 | 1.032 | - |
| F=100 Hz | I, mkA | 292.2 | 194.8 | 97.4 | - |
| | P, W | 588.8 | 614.2 | 423.8 | - |
| | A, mCi/hour | 2.042 | 2.659 | 2.065 | - |
| F=150 Hz | I, mkA | 438.3 | 292.2 | 146.1 | - |
| | P, W | 883.2 | 921.3 | 635.7 | - |
| | A, mCi/hour | 3.062 | 3.989 | 3.097 | - |

Table 2: Beam parameters, absorbed power and Cu-67 yield in the Zn target ($\Delta_c$=4 mm, HFP = 12 MW)

| | | | | | |
|---|---|---|---|---|---|
| | $I_{imp}$, mA | 1053 | 789.5 | 526.3 | 263.2 |
| F=50 Hz | I, mkA | 194.7 | 146.1 | 97.4 | 48.7 |
| | P, W | 610.4 | 658.6 | 586.5 | 363.6 |
| | A, mCi/hour | 1.441 | 2.183 | 2.240 | 1.528 |
| F=100 Hz | I, mkA | 389.4 | 292.2 | 194.8 | 97.4 |
| | P, W | 1220.8 | 1317.2 | 1173.0 | 727.2 |
| | A, mCi/hour | 2.882 | 4.366 | 4.480 | 3.056 |
| F=150 Hz | I, mkA | 584.1 | 438.3 | 292.2 | 146.1 |
| | P, W | 1831.2 | 1975.8 | 1759.5 | 1090.8 |
| | A, mCi/hour | 4.323 | 6.549 | 6.720 | 4.584 |

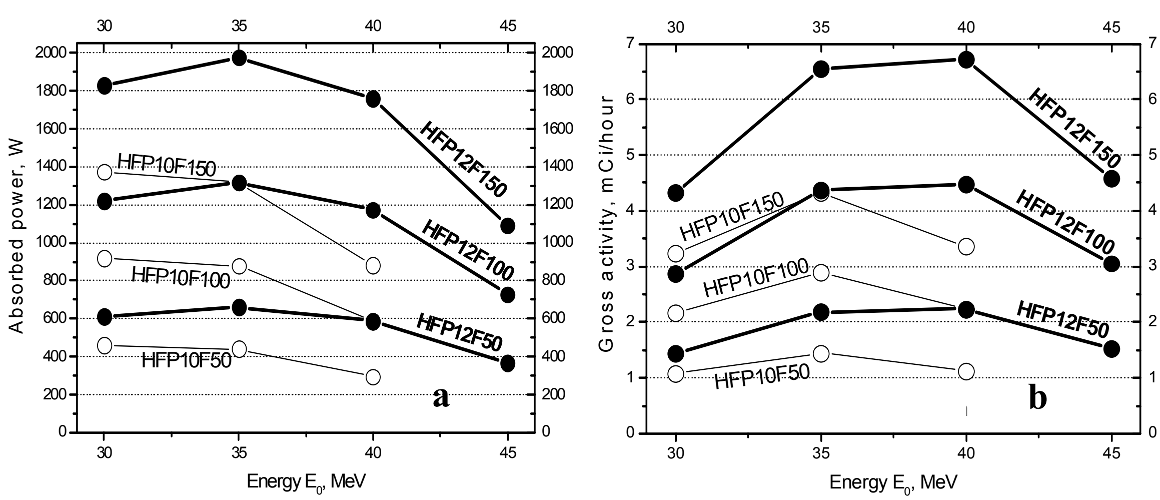


Figure 2: Absorbed power (a) and activity (b) of Zn target ($\Delta_c$=3 mm).

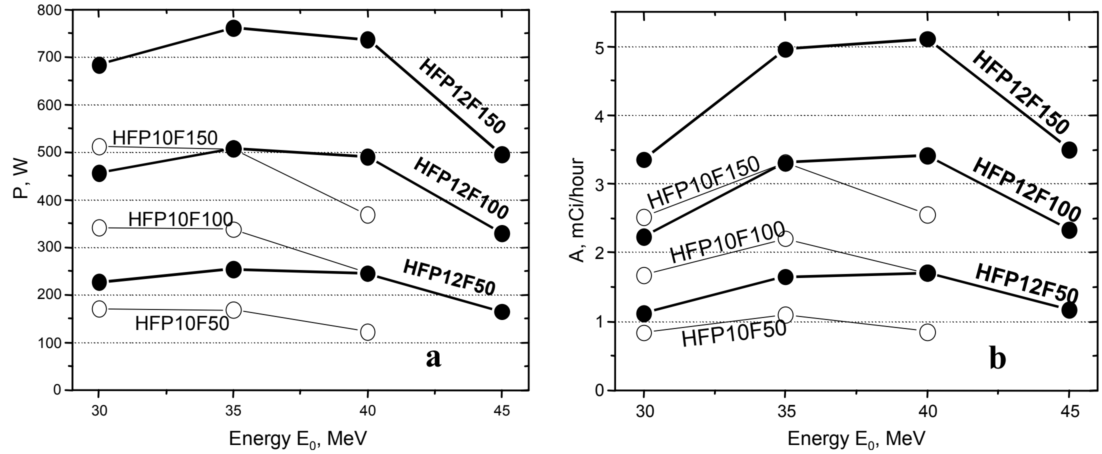


Figure 3: Absorbed power (a) and activity (b) of Zn target ($\Delta_c$=6 mm).

Table 3: $P_m$=500 W, $\Delta_c$=6 мм, F=150 Hz

| HFP,MW | $E_0$,MeV | P,W | A,mCi/hour |
|---|---|---|---|
| 10 | 30 | 513.6 | 2.517 |
| 10 | 35 | 507.6 | 3.309 |
| 12 | 45 | 495.3 | 3.504 |

Table 4: $P_m$=800 W, $\Delta_c$=6 мм, F=150 Hz

| HFP,MW | $E_0$,MeV | P,W | A,mCi/hour |
|---|---|---|---|
| 12 | 30 | 684.3 | 3.354 |
| 12 | 35 | 761.4 | 4.962 |
| 12 | 40 | 737.1 | 5.118 |
| 12 | 45 | 495.3 | 3.504 |

Table 5: $P_m$=1000 W, $\Delta_c$=6 мм, F=150 Hz

| HFP,MW | $E_0$,MeV | P,W | A,mCi/hour |
|---|---|---|---|
| 12 | 30 | 845.8 | 3.741 |
| 12 | 35 | 992.7 | 5.483 |
| 12 | 40 | 945.0 | 5.645 |
| 12 | 45 | 626.5 | 3.877 |

Table 6: $P_m$=1400 W, $\Delta_c$=6 мм, F=150 Hz

| HFP,MW | $E_0$,MeV | P,W | A,mCi/hour |
|---|---|---|---|
| 12 | 30 | 1177.0 | 4.081 |
| 12 | 35 | 1382.0 | 5.983 |
| 12 | 40 | 1271.4 | 6.195 |
| 12 | 45 | 823.9 | 4.273 |

## DISCUSSION

The preliminary calculations have shown that that at fixed converter thickness and target dimensions the isotope yield increases with an increasing electron energy [3]. Our present results indicate that the consideration of the accelerator LC gives rise to the peak in this energy dependence (see Figs.2b, 3b). An additional restriction on the choice of target activation conditions stipulates the permissible value of absorbed radiation power $P_m$. In particular, it becomes necessary to make the converter thickness greater than in the case that provides the highest rate of isotope generation.

## CONCLUSION

- The composition of output devices and the isotopic target activation conditions in photonuclear production must be chosen with due regard for both the load characteristic of the electron accelerator and the conditions of target cooling.
- An efficient method for optimizing the target activation conditions may be the simulation with the program system PENELOPE supplemented with the database on the corresponding photonuclear reaction cross sections.
- The undertaken analysis of production conditions for the Cu-67 isotope at the KIPT accelerator KUT-30 has shown that the increase of the permissible absorbed power in the target from 500 W up to 1400 W provides nearly an 80% increase in the yield of Cu-67.

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