# POSSIBILITY OF SOME RADIONUCLIDES PRODUCTION USING HIGH ENERGY ELECTRON BREMSSTRAHLUNG

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Abstract

The method of some radio nuclides production using high energy Bremsstrahlung of electron accelerators and determination of photonuclear reaction yield and specific activity for some radio nuclides is described. Photonuclear reaction yield and specific activity for some radio nuclides were determined for $^{117m}$Sn, $^{111}$In and $^{195m}$Pt.

Based on the experimental data obtained at low energy ($E_{e^-}$<30 MэB) electron accelerators as well as the microtron MT-25 (FLNR, JINR) with the power 0.5 kW, photonuclear reaction yields are estimated for some radio nuclides for the linear electron accelerator ($E_{e^-}$ = 75 MeV) of the IREN facility, FLNP JINR at irradiation of high purity platinum and tin metals.

## INTRODUCTION

At present, the requirements for an acceptable radionuclide are still considerably high. The nuclear reactors and cyclotrons are mainly used for the radionuclide production. However, they are not able to produce all the required types of radio nuclides, therefore, electron accelerators as Linac and Microtron, that can be produced radio nuclides using the Bremsstrahlung, are suitable complements.

Properties of the radionuclide $^{117m}$Sn are acceptable for clinical and therapeutic use: the short half-life of 13.6 days is necessary to minimize the patient exposure, the gamma emission of photons of 158.4 keV (84 %) for imaging, and abundance (116 %) of low energy (127-129, 152 keV) Auger and conversion electrons for delivering a high radiation dose to sites of a bony metastatic disease [1, 2]. Also the platinum radionuclide $^{195m}$Pt can be used for cancer diagnosis and therapy.

The yields for a number of radio nuclides produced by the Bremsstrahlung beam irradiation were measured by different groups. Oka et al. [3] measured the yields of radio nuclides induced by the ($\gamma$, $n$) reactions with the 20 MeV Bremsstrahlung from a linac on 37 elements. Analogous measurements were performed at the Czech microtron by Randa et al. [4] with the 19 MeV Bremsstrahlung beam. Detailed measurements were also performed by Gerbish et al. [5] and Thiep et al. [6] at the microtron in Dubna, FLNR, JINR for practically all natural nuclides at different electron 14, 18 and 20 MeV energies. Properties and activity yields of radio nuclides obtained from photonuclear reaction data are based exclusively on experimentally obtained results for the majority of elements and are presented in book by Segebade et al. [7].

## THE AIM OF THESE EXPERIMENTS

In the work will try to give some information on the possibility of application of the Bremsstrahlung beam of the linac of the new Intense REsonance Neutron pulsed source (IREN) for fundamental and applied nuclear physics is being realized in the 2008 in Frank Laboratory Neutron Physics of JINR, Dubna.

**ACCELERATOR**

The methods of multielemental photon activation analysis (MPAA) and radionuclide production will be developed at the Linac of the IREN facility.
Some technical characteristics for the Linac of the IREN facility are as follows:

- Maximum Energy of Electrons - 75 MeV
- Peak current - 2.84 A;
- Pulse frequency - 50 Hz;
- Electron burst width (FWHM) - 140 ns.
- Power - 1,1 kWt

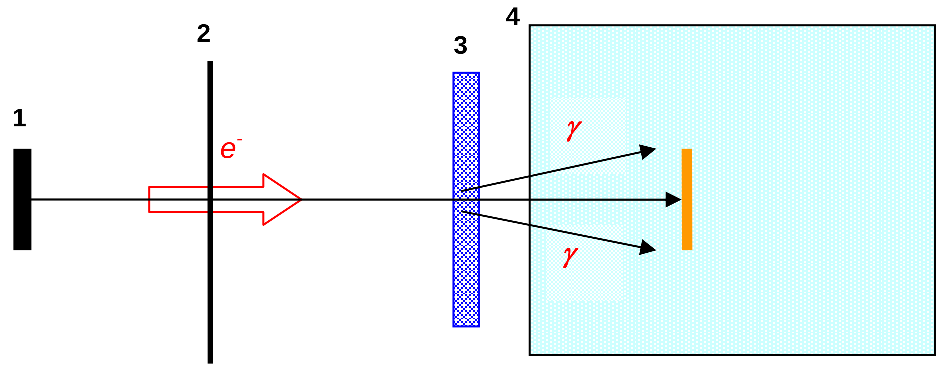



Fig 1. Simple geometry of radiation target by bremsstrahlung
1 - electron source; 2 - exit foil ( ~ 0,1-0,3 mm thick Ti); 3 - converter (W or Pt plate ~ 2,5 and 5 mm); 4 – target.

A water cooled tungsten or platinum target has been used for the Bremsstrahlung converter. The temperature on the surface of the W or Pt disk of the target must be lower than ~900 $^0$C.

The preliminary methodical experimental investigation was carried out on the cyclic electron accelerator Microtron MT-25 of FLNR, JINR. The Microtron MT-25 was used as the Bremsstrahlung source to determine specific activities and yields of the photonuclear reactions. The 0.57 kW power irradiation targets of the Microtron MT-25 were operated with the electron beam -15 μA current and 23.5 MeV energies. The results of methodical study are given in the present work.

## EXPERIMENTAL PROCEDURE

To estimate the activity and yield of the radionuclide $^{117m}Sn$, $^{111}In$, $^{195m}Pt$ production, the natural pure tin, platinum and enriched $^{118}Sn$ (98.5 %) isotope have been irradiated at the Microtron MT-25 in Dubna, FLNR, JINR by the bremsstrahlung beam of 23.5, 22, 21, 20, 19 MeV with the current of 13 – 14,5 μA during 1-2 h at the radial distance of 2 cm from the tungsten target (4 mm thick). For determination of photonuclear reaction specific activity and yields of Sn, Pt isotopes several experiments have been carried out:

| No | Bremsstrahlung Energy, (Mev) | Elements | Mass of sample, (mg) | Irradiation time, hours |
|---|---|---|---|---|
| 1 | 23,5 | Au - 1 | 5 | 1 |
| | | Zr - 1 | 1,2 | |
| | | Sn - 1 | 46,1 | |
| | | Sn - 118 (9) | 31,3 | |
| | | Cu - 1 | 49,5 | |
| 2 | 22 | Au - 2 | 6,2 | 1,5 |
| | | Zr - 2 | 0,6 | |
| | | Sn - 2 | 19,2 | |
| | | Cu - 2 | 48,8 | |
| 3 | 21 | Au - 3 | 6,9 | 1,5 |
| | | Zr - 3 | 0,7 | |
| | | Sn - 3 | 28,5 | |
| | | Cu - 3 | 44,2 | |
| | | Pt – 1 | 8,6 | |
| | | Sn - 112 | 12 | |
| 4 | 20 | Au - 4 | 5,5 | 1,5 |
| | | Zr - 4 | 4 | |
| | | Sn - 4 | 14 | |
| | | Cu - 4 | 35,8 | |
| | | Pt – 2 | 8,4 | |
| 5 | 19 | Au – 5 | 1,2 | 1,5 |
| | | Zr – 5 | 1 | |
| | | Sn – 5 | 37,4 | |
| | | Cu – 5 | 43,5 | |
| | | Pt – 5 | 6,3 | |
| 6 | 24,2 | Au – 6 | 1,2 | 1,5 |
| | | Zr – 6 | 1,1 | |
| | | Sn – 6 | 37,4 | |
| | | Cu – 6 | 39 | |
| | | Pt – 6 | 6,3 | |
| | | Sn - 118 (9) | 29,7 | |

Activity of the irradiated high purity natural platinum, tin and enriched $^{118}Sn$ samples and monitors were measured by HP Ge detectors' of the gamma spectrometer of FLNP, JINR with the energy resolution of 2 keV at gamma line of 1332 keV for $^{60}Co$ radionuclide. To the monitors of the high energy electron's Bremsstrahlung flux were used pure metal foils of Au, Cu and Zr. Gamma lines of the radio nuclides, which are detected from samples and monitors [2, 4] have been given in Table 1.

Equation (1) and (2) were used for calculation of specific activity, yield and integrated cross section of the photonuclear reaction.

$$S = \Delta N\gamma\varepsilon = \phi_{th}\sigma_{eff}\frac{N_A\theta w}{M}\left(1-e^{-\lambda t_{irr}}\right)e^{-\lambda t_d}\cdot\frac{\left(1-e^{-\lambda t_m}\right)}{\lambda}\cdot\gamma\varepsilon \qquad (1)$$

$$\sigma_{\text{int}} = \frac{A_s \cdot M(E_{\max} - E_{th})}{N_A \cdot \Phi_{th}};[MeV \cdot b] \qquad (2)$$

Where:
S - net peak area
$N_A$ - Avogadro's number ($mol^{-1}$)
θ - isotopic abundance of the target isotope (%)
γ - gamma ray abundance (i.e. probability of the disintegrating nucleus emitting a photon of this energy, photons per disintegration).
*w* - Mass of the irradiated element (g)
M - Atomic mass ($g.mol^{-1}$)
ε - Photo peak efficiency of detector (i.e. probability that an emitted photon of given energy will be detected and contribute to the photo peak in the spectrum).
$\sigma_{eff}$ - effective cross-section (mb or $10^{-27}$ $cm^2$)
$\phi_{th}$ - photon flux ($cm^{-2}.\mu A^{-1}.s^{-1}$)
$\lambda$ - decay constant
$t_{irr}$ - irradiation time (s)
$t_d$ - decay time (s)
$t_m$ - measuring time (s)
$A_s$ - Specific Activity (Bq/mg)
$E_{max}$ - Irradiation energy (MeV)
$E_{th}$ - Reaction threshold energy (MeV).

Table 1. Nuclear data of TIN (Sn) and PLATINUM (Pt) radioisotopes.

| Radionuclide and half–life | Main energy $E_\gamma$, keV | Intensity, % | Reaction | Threshold energy of reaction $E_\gamma$, MeV | Abundance of target, % |
|---|---|---|---|---|---|
| $^{117m}Sn$ 13.6 d | 158.40 | 84.00 | $^{117}Sn$ (γ,γ')<br>$^{118}Sn$ (γ,n)<br>$^{119}Sn$ (γ,2n) | -0.32<br>-9.65<br>-16.13 | 7.5<br>24.01<br>8.58 |
| $^{117m}Sn$ 13.6 d | 158.40 | 84.00 | $^{118}Sn$ (γ,n) | -9.65 | 98.50 |
| $^{111}In$ 2.83 d | 171.29<br>245.35 | 91.00<br>94.00 | $^{112}Sn$(γ,p) | -7.73 | 0.95 |
| $^{195m}Pt$ 4.1 d | 98.86<br>129.74 | 11.01 | $^{195}Pt$ (γ,γ')<br>$^{196}Pt$ (γ,n)<br>$^{198}Pt$ (γ,3n) | -0.26<br>-8.18<br>-21.60 | 33.80<br>25.20<br>7.19 |

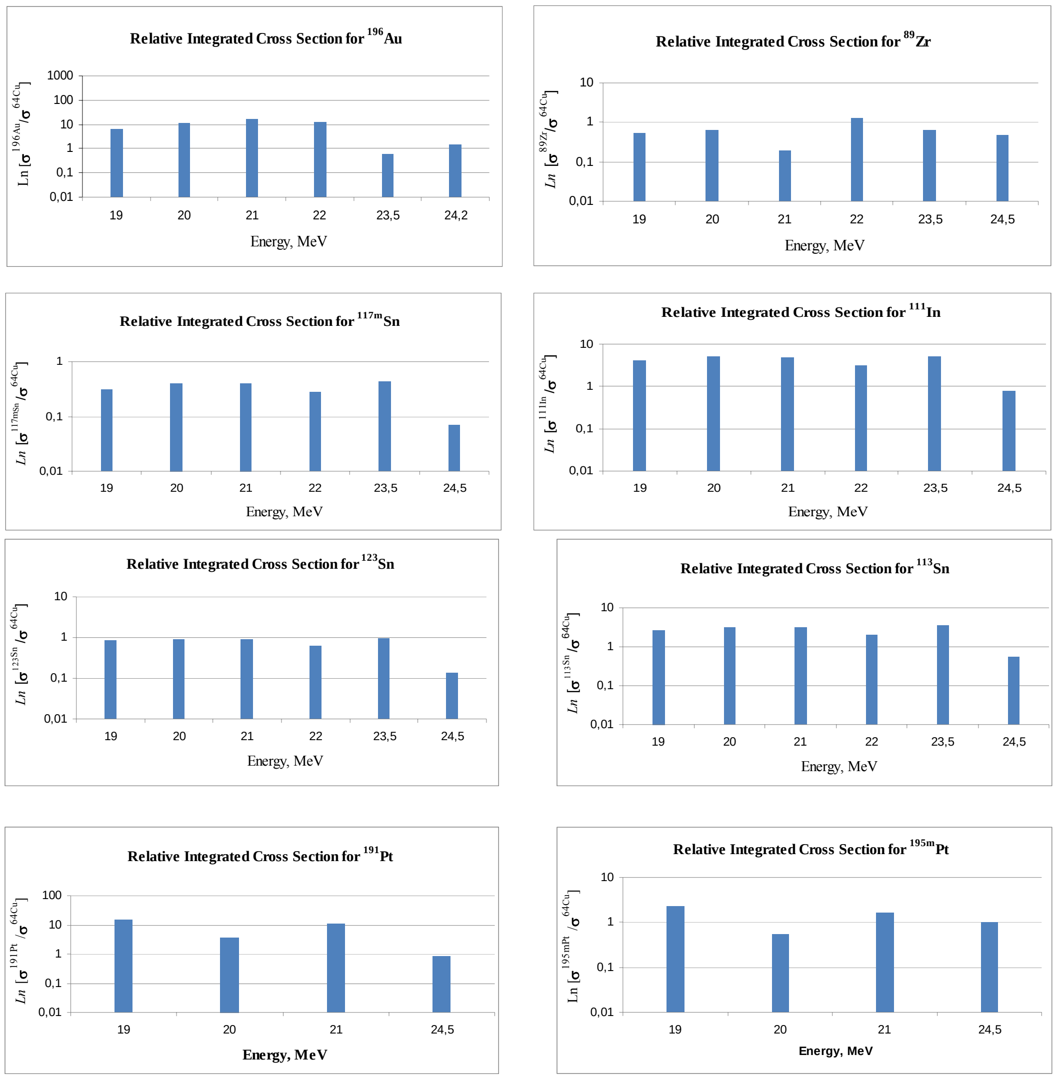
Radionuclide of this class is therapeutically and diagnostically useful in skeletal imaging and for the radiotherapy of bone tumors and other disorders [9-12].

From the measured gamma spectrum data the experimental photonuclear reaction activity and yield have been determined for radio nuclides $^{117m}Sn$; $^{111}In$ and $^{195m}Pt$. Their experimental values are shown in Table 2.

Table 2. Experiment's results of specific activity and yield for some radio nuclides.

| **No** | **Energy of Bremsstrahlung, Eγ [MeV]** | **Element** | **Radio-nuclide** | **Specific activities** *A, [Bq/mg]* | **Yields** *Y, [Bq/ [μA mg h]* | **Isomer's Ratio R**, *[Ym/Yx]* | **Relative integrated cross section,** *[$\sigma^x/\sigma^{64Cu}$]* |
|---|---|---|---|---|---|---|---|
| 1 | 23.5 | Sn – 1 | $^{117m}Sn$ | 8.17E+05 | 5.45E+04 | | 0.44 |
| | | | $^{111}In$ | 8.76E+06 | 5.84E+05 | 0.09 | 5.1 |
| | | | $^{113}Sn$ | 7.01E+06 | 4.68E+05 | 0.116 | 3.46 |
| | | | $^{123}Sn$ | 1.52E+06 | 1.01E+05 | 0.54 | 0.93 |
| | | Sn -118 | $^{117m}Sn$ | 5.77E+05 | 3.85E+04 | | 0.31 |
| 2 | 22 | Sn - 2 | $^{117m}Sn$ | 3.14E+05 | 1.39E+04 | | 0.28 |
| | | | $^{111}In$ | 3.15E+06 | 1.40E+05 | 0.09 | 3.12 |
| | | | $^{113}Sn$ | 2.62E+06 | 1.16E+05 | 0.12 | 2.01 |
| | | | $^{123}Sn$ | 6.17E+05 | 2.74E+04 | 0.51 | 0.64 |
| 3 | 21 | Sn - 3 | $^{117m}Sn$ | 3.02E+05 | 1.33E+04 | | 0.40 |
| | | | $^{111}In$ | 3.30E+06 | 1.47E+05 | 0.09 | 4.84 |
| | | | $^{113}Sn$ | 2.60E+06 | 1.16E+05 | 0.115 | 3.12 |
| | | | $^{123}Sn$ | 6.02E+05 | 2.68E+05 | 0.49 | 0.92 |
| | | Pt – 1 | $^{195m}Pt$ | 6.56E+05 | 2.92E+04 | | 1.63 |
| | | | $^{191}Pt$ | 4.46E+06 | 1.98E+05 | 0.15 | 10.77 |
| 4 | 20 | Sn - 4 | $^{117m}Sn$ | 2.75E+05 | 1.20E+04 | | 0.41 |
| | | | $^{111}In$ | 2.99E+06 | 1.30E+05 | 0.09 | 5.08 |
| | | | $^{113}Sn$ | 2.33E+06 | 1.02E+05 | 0.12 | 3.18 |
| | | | $^{123}Sn$ | 5.07E+05 | 2.21E+05 | 0.54 | 0.89 |
| | | Pt - 3 | $^{195m}Pt$ | 1.96E+05 | 8.55E+03 | 0.15 | 0.56 |
| | | | $^{191}Pt$ | 1.30E+06 | 5.70E+04 | | 3.62 |
| 5 | 19 | Sn - 5 | $^{117m}Sn$ | 1.1E+05 | 3.77E+03 | | 0.31 |
| | | | $^{111}In$ | 1.25E+06 | 4.29E+04 | 0.08 | 4.12 |
| | | | $^{113}Sn$ | 1.05E+06 | 3.59E+04 | 0.105 | 2.70 |
| | | | $^{123}Sn$ | 2.49E+05 | 0.85E+04 | 0.44 | 0.84 |
| | | Pt - 3 | $^{195m}Pt$ | 4.04E+05 | 1.38E+04 | 0.15 | 2.23 |
| | | | $^{191}Pt$ | 2.66E+06 | 0.91E+05 | | 14.6 |
| 6 | 24.5 | Sn – 6 | $^{117m}Sn$ | 9.73E+04 | 4.11E+03 | | 0.07 |
| | | | $^{111}In$ | 1.07E+06 | 4.51E+04 | 0.09 | 0.78 |
| | | | $^{113}Sn$ | 8.69E+05 | 3.67E+04 | 0.11 | 0.54 |
| | | | $^{123}Sn$ | 1.86E+05 | 7.86E+03 | 0.52 | 0.14 |
| | | Pt – 6 | $^{195m}Pt$ | 8.03E+05 | 3.39E+04 | | 1.0 |
| | | | $^{191}Pt$ | 6.95E+06 | 2.93E+05 | 0.116 | 0.84 |
| | | Sn-118 | $^{117m}Sn$ | 5.43E+5 | 2.29E+4 | | 0.06 |

Fig.3. The distribution of relative integrated cross section $[\sigma^{x}/\sigma^{64Cu}]$ for some radio nuclides in irradiation energies of Bremsstrahlung.




## DISCUSSION AND CONCLUSION.

1. Results of the experiments have shown a possibility of the $^{117m}$Sn, $^{111}$In, $^{195m}$Pt radionuclide production using the Bremsstrahlung of high energy electron accelerators. In case of irradiation of the natural pure tin, radioisotopes $^{117m}$Sn and $^{111}$In have been produced, which both are useful for medical purposes.
2. The experimental yield of photonuclear reaction is several times higher than when an enriched $^{118}$Sn (98.5 %) isotope is used in the target, and from the gamma spectrum can see

the gamma line of 158.4 keV of only one radionuclide $^{117m}Sn$. The photonuclear reaction yields of the $^{111}In$ have been compared with the data determined in other works and they have sufficient coincidences.

3. The isomeric ratio of $^{117m}Sn$ was estimated from the experimental data of activities of 158.4 ($^{117m}Sn$); 391.7 ($^{113}Sn$) and 1089 ($^{123}Sn$) keV energy gamma lines. The isomeric ratios for $^{117m}Sn$ were estimated and determined 0,114 ± 0.005 and 0,506 ± 0.038 for the radio nuclides $^{113}Sn$, $^{123}Sn$, correspondingly. A isomeric ratio for $^{195m}Pt$ determined 0.141± 0.005.
4. The activities and yields of the $^{117m}Sn$ and $^{111}In$ radio nuclides will be (10 times) increased at the Bremsstrahlung beam of the Linac of the IREN facility, which is constructed in FLNP, JINR.
5. In the Table 2. have shown the calculated specific activities, photonuclear reaction yields and relative integrated cross section for the radio nuclides ($^{196}Au$, $^{89}Zr$, $^{117m}Sn$, $^{111}In$, $^{113}Sn$, $^{123}Sn$, $^{195m}Pt$ and $^{191}Pt$).
6. In Fig. 3 have given the histograms of distribution for relative integrated cross section of the above mentioned radio nuclides in absorption energies of Bremsstrahlung.
7. From the calculated integrated cross section can be determined isomeric ratio and $\sigma(\gamma,n)/\sigma(\gamma,p)$ for *Sn* have find 0.088 ± 0.004.
8. From the results of experiments can concluded the possibility production more useful radio nuclides as well as $^{117m}Sn$, $^{111}In$, and $^{195m}Pt$ for nuclear medicine, science and technology using high energy Bremsstrahlung of electron accelerators.

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