A HIGH-CURRENT POSITRON SOURCE

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The positron sources now in use have an intensity of about 10^6-10^8 e^+/s or a positron current of about 10^{-13}-10^{-11}A[1]. This is less than the current of electron and ion beams used in science and technology by 10-20 orders of magnitude. A high-current, quasistationary positron source can be created on the basis of a $_{29}Cu^{64}$ isotope produced in irradiation natural copper by thermal neutrons in a nuclear reactor [2,3]. If the irradiation is performed in the central cell of the highest-flux channel of an SM-3 reactor for several days, the $_{29}Cu^{64}$ specific activity will be as high as 130-190 Ci/g at neutron flux density of about $A \approx 1.5\ 10^{15}$ cm^{-2} s^{-1}. In such a case the starting material (a rod made from copper of natural isotopic composition) must have a diameter d≤1cm and a length L≤30cm. The standard TUE targets must be inserted in the cells. Thus, the total mass of copper Cu^{64} that can be produced in a single irradiation run amounts to about 200g. Its total activity will be 20-30 kCi, corresponding to a positron current of 10^{-3}-10^{-4} A. Indeed, only 0.1% of positrons can escape from the cylinder specimen; the remaining positrons are used in the bulk. To increase the yield of positrons the specimen withdrawn from the reactor must be transformed to foils, for example, by a magnetron sputtering technique in a "hot" chamber. If the foil thickness is 20μm, the yield of positrons will be as high as $100\%\cdot\exp(-17\cdot 8.9\cdot 0.66^{-1.14}) \approx 60\%$ of the theoretically possible value. The area of the foil will be $2m^2$.

Can the quasistationary positron current exceeding 10^{-3}-10^{-4}A be reached on the basis of the present state of the art? To do this the following scheme should be realized: a quasistationary isotope source → a means based on plasma mirror traps (for example, of the open-trap type) for accumulating and retaining positrons → a means for fast extracting positrons from the trap. If the positron source provides a positron current of 10^{-3}-10^{-4}A, while the plasma trap is capable of efficiently trapping and retaining positrons for 10-100s [4] and then being opened in 10^{-3}-10^{-4}s, the positron current pulse will be as high as 1 to 1000A. Thus, the solution of the high-current positron source problems lies at the junction of several engineering branches including production of highly active isotopes, plasma traps and acceleration engineering (e^+-sources).

Let us consider two schemes of sources.

1. A POSITRON SOURCE BASED ON FOCUSING THE DECAY PRODUCTS FROM AN EXTENDED $\beta^{\pm}$-ACTIVE ISOTOPE IN A MAGNETIC AND AN ELECTRIC FIELDS.

The simplest solution for the problem of focusing the positrons emitted by the foil consists in using a convergent magnetic field. An electric field applied towards the neck of the mirror will evidently improve such a system [4-5]. In this case the value of the transit angle becomes dependent on the positron energy

$$\mathrm{Sin}^2\theta < \frac{(E + e\Delta\varphi)^2 - m^2c^4}{R_m(E^2 - m^2c^4)},$$

where E is the total energy of positron; R_m is the mirror ratio; $\Delta\varphi$ is an accelerating potential difference. At the energies

$$e\Delta\varphi / E_F > \left(R_m - \left(mc^2/E_F\right)^2 \cdot (R_m - 1)\right)^{1/2} - 1,$$

all the positrons will travel through the mirror regardless of the angle of inclination of their trajectory. Here E_F is the maximum energy in the radiation spectrum (Fermi energy).

The quasistatic focusing system was analyzed for the maximum feasible parameters: an accelerating potential, $e\Delta\varphi$, of up to 10MeV, a maximum magnetic field, B_{max}, of up to 100kG and a length of 5-10m. Therefore, the results obtained demonstrate the ultimate in the static focusing that can be attained by this way.

Figure 1 shows the current delivered to the target as a function of the potential difference (E_F =1.17MeV, R_m=100, B_{max} =100kG). The current delivered to the target and its density as a function of the mirror ratio at $e\Delta\varphi$ =10MeV and B_{max}=100kG are shown in Figs. 2 and 3.

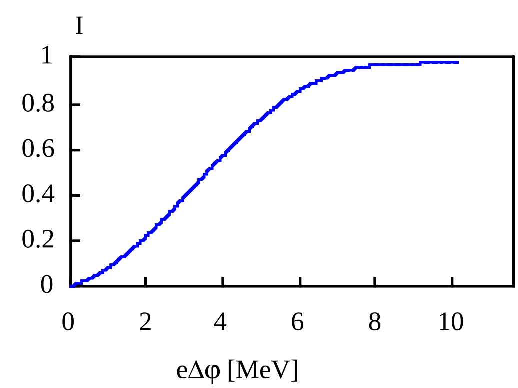

Fig.1

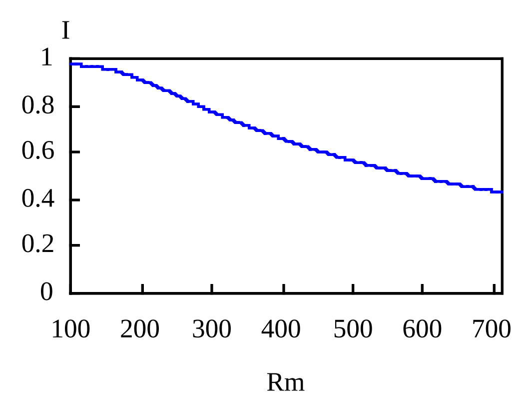

Fig.2

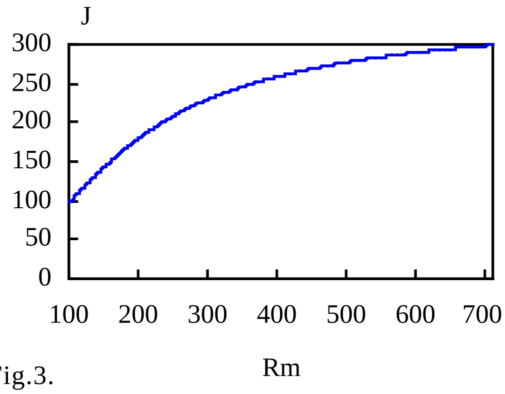

Fig.3.

The theoretical calculations and the numerical simulations showed that for a $_{29}Cu^{64}$ foil the beam can be focused onto an area of 24-25 times less than the initial radius by losing up to 50% of the initial current. Despite the high mirror ratio (≈600) the drift theory is still applicable to this case (to an accuracy of 10%) and the beam formation process can be easily described theoretically.

For a foil area of $2m^2$, a positron current of 10^{-3}-10^{-4}A and m≈ 200g the focusing spot has a radius of about 2.8cm and J ~ $3\cdot10^{-5}$-10^{-6}A/cm^2.

A small source made of foil (m≈ 0.36g, A≈ 10^{15}, foil radius ≈2.5cm, foil thickness d=20μm) allows a current of $10^{12}e^+$/s to be focused onto an area of radius R_f ~0.1cm.

The strong longitudinal and, first of all, transverse heating of the positron flux ($T_\perp \approx e\varphi_{max}$) can be assigned to the shortcomings of the scheme. If we attempt to use the beam focused in such a way as a source of annihilation γ-quanta and direct it on to a plane target, the positrons penetrating the substance will thermolize to form a hemisphere of about 1cm diameter in the volume of the target. It is this hemisphere that will be a volume source of annihilation γ-quanta. On the other hand, severe difficulties appear in transporting the focused beam. Finally, because of the considerable geometric dimensions of the foil a strong constant electric and magnetic fields should be created in a large volume. True, the foil could be convoluted to form a cylinder [8], however, in so doing no great gain could be obtained.

2. A HIGH-INTENSITY "TRANSPARENT" POSITRON SOURCE * ("SHASHLYK") [6-7]

To extract positrons from a massive β^+-active specimen it can be made as a system of β-transparent elements (for example, foils d~ 10-20 μm in thickness) with sufficiently small cross-sectional dimensions so that outgoing beam could be easily focused (see Fig.4).

If we assume that all the foils are similar and that the same potential differences $e\Delta\varphi_{i,i+1}$ sufficient to compensate for the angular scattering applied between the foils, then at a fixed total potential difference there exists

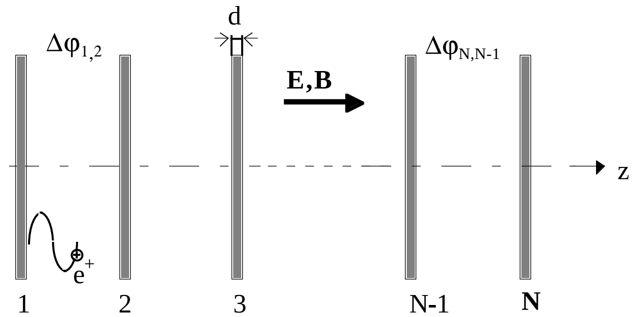

Fig.4.

an optimal number of foils for which the current at the exit is maximum.

Figure 5 shows the optimal output current normalized to the half activity of a 20-μm-thick foil in the absence of self-absorption as a function of the thickness of the individual foil. The numerals denote the optimal number of foils for the given voltage and the given thickness. The curves differ in the value of applied voltage:

$e\varphi_\Sigma$=500keV, $e\varphi_\Sigma$=1MeV,
$e\varphi_\Sigma$ =5MeV, $e\varphi_\Sigma$ =10MeV.

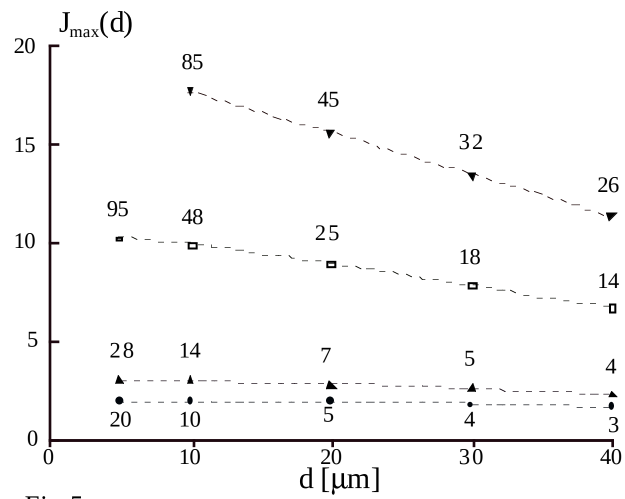

Fig.5

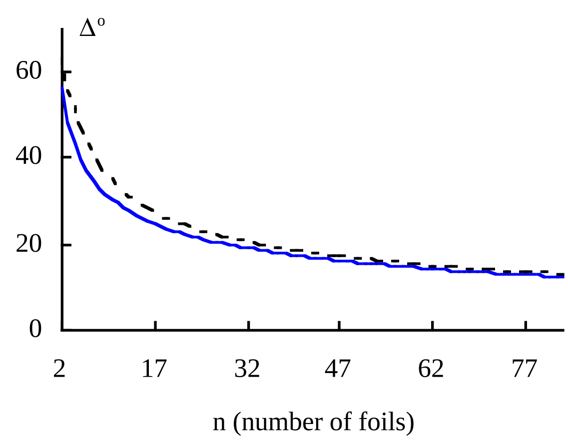

Fig.6

* Shaslyk is a culinary term standing for the pieces of mutton roasted on a spit

The angular width of the distribution of the partial current as a function of the number of foils through which the beam has passed is plotted in Fig. 6. The parameters of the system are: $e\varphi_\Sigma = 20$MeV, $d=20\mu$m, $N=83$. The solid and dotted curves correspond to the numerical and analytical calculations, respectively.

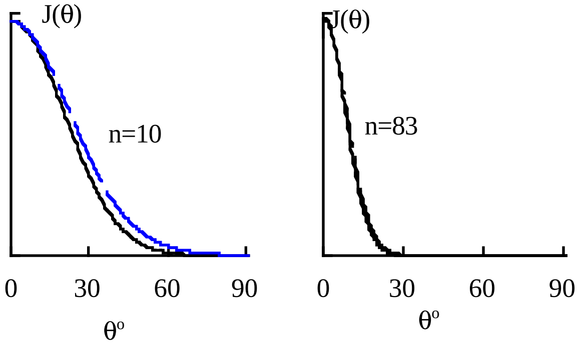

Fig.7

Figure 7 shows the angular distribution of the partial current. Different plots correspond to the different numbers of the foils n through which the beam has passed.

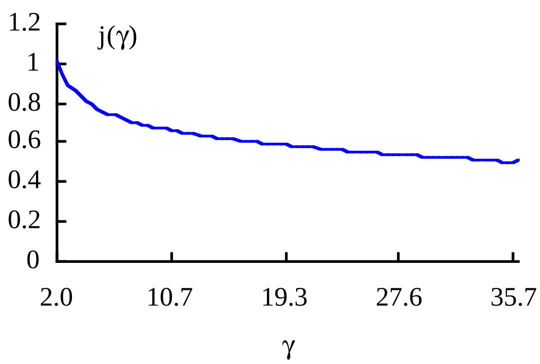

Fig.8

Figure 8 shows the energy distribution function of the total current $j(\gamma)$. Here γ is total energy of positrons normalized on mc^2. The steep drop of $j(\gamma)$ at great γ corresponds to a weak absorption of high-energy particles by the foils.

We offer the concrete example basing on the numerical calculations in the framework of a source model described in Section 2. Let the energy of an accelerator be 20MeV. Choose the isotope $_{29}Cu^{64}$. Let the area of each foil be $10cm^2$ and its thickness - 20μm. Then the optimal number of the foils ~ 80. If the irradiation occurs in the highest-flux channel of an SM-3 reactor (the flux is about 10^{15} n/(cm^{2}s)), each of such foils emits about $5\Sigma 10^{11}$ e^+/s on one side. The total positron current at the exit will be ~$2\Sigma 10^{13}$, that is, ~50% of the half activity of all the foils (with allowance for the self-absorption). The majority of the positrons having passed through the last foil are concentrated within an angle 20º. The energy distribution at the exit from the source is in the form of a “plateau” with a dispersion of 20MeV.

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