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A Low-Neutron-Background Slow-Positron Source*

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Abstract. The addition of a thermionic rf gun [1] and a photocathode rf gun will allow the Advanced Photon Source (APS) linear accelerator (linac) [2] [3] to become a free-electron laser (FEL) driver [4]. As the FEL project progresses, the existing high-charge DC thermionic gun will no longer be critical to APS operation and could be used to generate high-energy or low-energy electrons to drive a slow-positron source. We investigated possibilities to create a useful low-energy source that could operate semi-independently and would have a low neutron background.

I. INTRODUCTION

The APS electron linac was designed to accelerate 30-ns-long pulses containing 50 nC of charge to an energy of 200 MeV. The 500-W beam impinges on a 7-mm-thick water-cooled tungsten converter target and the resulting positrons are further accelerated to 450 MeV. The nominal electron beam power can be increased either by increasing the quantity of accelerated charge or by increasing the beam energy. Slow-positron production rates at the APS linac for a 400-MeV electron beam were estimated to be 3×10^{11} positrons per second with an optimized five-layer target [5], [6]. High-energy drive beams result in high beam power and high positron-production rates at moderate current, thus reducing space charge effects. Accelerator studies indicate that the APS linac could produce up to 35 kW of beam power when run at high energy and in long-pulse mode [7]. The clear disadvantage of high-energy electron beams is the potential for severe component activation near the target. Activation can be reduced if the driving electron beam energy is low but still adequate for electron-positron pair production. Few of the photons will be energetic enough to generate photoneutrons. The neutron yield per incident electron in a high-Z target is low for energies below 14 MeV. The photoneutron cross-section for tungsten is about 400 mb for 14-MeV photons and becomes negligible for photons of energy less than 6 MeV [8]. For one-radiation-length-thick targets, measurements indicate that there are 2.5×10^{-4} neutrons per 14-MeV electron [9].

The linac is being upgraded with a new low-emittance injector to drive an FEL, thus the original injector elements could be used for slow-positron production. Positron yield can be increased by optimizing the target design for a given beam power. A candidate target geometry for 14-MeV electrons was chosen and was optimized by simulation.

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II CHOICE OF INCIDENT BEAM ENERGY AND TARGET GEOMETRY

Most of the incident electron beam should penetrate the target for efficient positron production. The number of backscattered electrons is independent of target thickness, decreases exponentially with increasing electron energy, and is negligible for energies greater than 8 MeV. For energies below 3 MeV, more than 0.5% of the incoming particles are scattered back upstream. We chose 10 and 14 MeV as the energies to study after considering the tungsten photoneutron cross section and the existence of local electron sources at these energies where we can perform beam tests. Figure 1a) shows the photon energy distribution from 20000 14-MeV electrons impinging on a 1.2-mm-thick tungsten target. An energy cutoff of 1.0 MeV was applied to the distribution prior to histogramming, since photons below 1.0 MeV are incapable of pair production. The distribution peaks at 1.5 MeV and has a standard deviation of 2.4 MeV. Less than 9×10^{-2} photons per electron have energies greater than 6 MeV.

In our simulations, we chose electron energies between 8 and 14 MeV. The simulations were performed with EGS4 [10], together with a C-language user interface code [11]. We examined the positron production rates for several electron energies and target geometries. First, the best single-target length was determined. This length was then used as a basis for determining the total length of a multilayer target candidate. The forward positron production rate as a function of single-block target thickness for 8- and 14-MeV electrons is shown in Figure 1b). The production peaks at ≈ 2.5 mm for both electron energies. Variations in the lower-energy curve are due to statistical fluctuations.

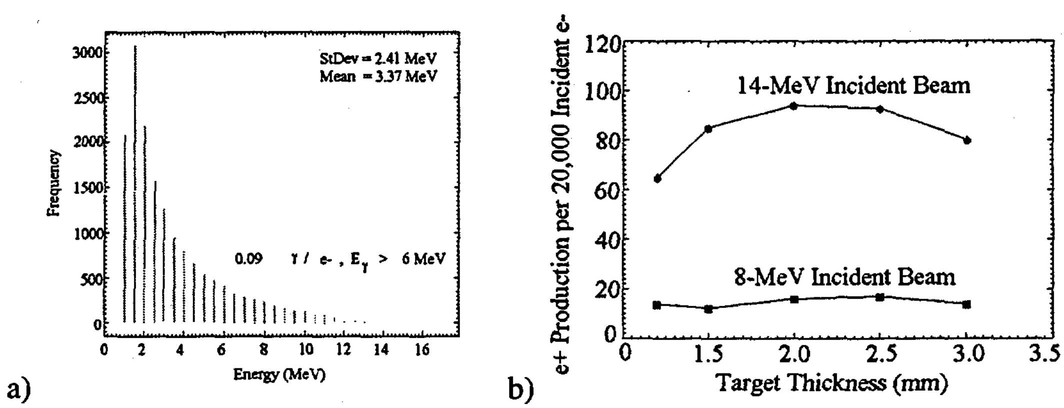

Figure 1: a) Photon energy distribution from 20000 14-MeV electrons impinging on a 1.2-mm tungsten target. **B)** Forward positron production as a function of single-block target thickness for 8- and 14-MeV electrons.

The 400-MeV simulation results were used to guide the 14-MeV multilayer target optimization. Positron production as a function of target thickness, and output electron and photon mean energy variations were analyzed to determine the optimal multilayer target geometry. Four target configurations, C1 to C4, were analyzed. Each contained five segments of varying thicknesses and had a fixed total length of 10.5 mm. The 10.5-mm length was based on the thickness of the optimized single-block tungsten target.

The five segments in Cl are 3.5, 2.625, 2.625, 8.75, and 8.75 mm long. C2 is a 3.5-/1.75-/1.75-/1.75-/1.75-mm target; C3, a 2.625-/2.625-/0.875-/0.075-mm target; and C4, a 4.375-/2.625-2.625-/0.437-/0.437-mm target. The highest number of positrons after the first segment occurs in C4, whose first segment is 40% of the total length. The overall highest positron yield is also achieved in C4. To determine consecutive segment lengths in a low energy target, segment-to-segment changes in positron production were examined. In addition, these changes were related to changes in the respective segment lengths, changes in the mean output electron energy and the mean photon energy.

In Fig. 2a, the changes in positron yield after each segment are shown for the four configurations. The yield refers to positrons with energies ≤ 6 MeV. The highest yield change after the first segment corresponds to C1, where the second segment is 25% shorter than the first segment. The second highest change occurs after the third segment of C3, where the length is unchanged between consecutive segments. The positron yield and its differentials also depend on the photon and electron mean energy variations. For the geometries analysed, the positron count changes most when the mean energy changes by 40% in the first layers and by 10% in the last layers. Figure 2b) shows the positron yield per segment for the optimized 14-MeV target, based on results from the above.

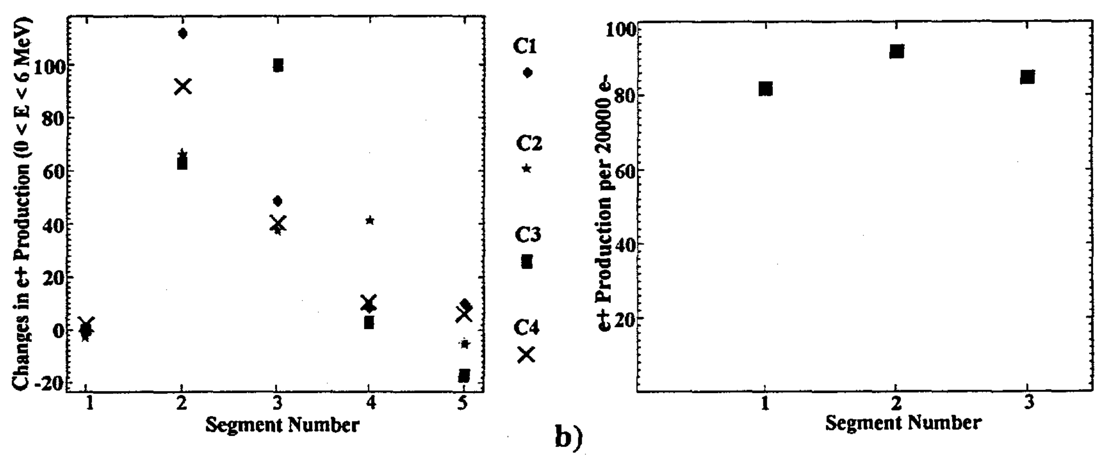

Figure 2: a) Changes in positron yield after each segment for four configurations at 400 MeV. **b)** Positron yield per segment for the optimized 14-MeV target, based on **a)**.

This analysis and the single-block target results suggested a three-layer target with segment thicknesses of 1.2, 0.9, and 0.9 mm. Further simulations showed that the positron count could be increased by 26% when the last segment is 0.6 mm long. For the optimized 1.2-/0.9-/0.6-mm target, the total number of positrons with energy less than 6 MeV is about 3% of the number of incident electrons.

CONCLUSIONS

A slow-positron source with reasonable slow-positron yield and with a relatively low neutron background could be constructed. For an incident 14-MeV electron beam, we estimate that a flux of 10^7 positrons per second can be achieved, assuming a conservative moderation efficiency of 10^{-3}.

Plans are now underway to measure the positron and slow-positron yields at a local facility with beam characteristics similar to those considered in this paper. Low-energy electrons have the advantage that the source could be semi-independent. Various source configurations have been investigated. Slow-positron operation in parallel with other APS operations is easily possible in several configurations.

An additional advantage of the low-energy driver is that extraction and guide voltages for the unmoderated positrons are lower, since positrons are produced at lower energies. The disadvantage is in lower positron production rates. The beam power and thus the production rate can be improved by increasing the electron current. At high power and low energy, target ablation may be a problem. Detailed thermal analysis must be carried out, and careful monitoring of the target and support structures must be envisioned.

V. ACKNOWLEDGMENTS

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VI. REFERENCES

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