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# A DESIGN FOR A HIGH INTENSITY SLOW POSITRON FACILITY USING FORWARD SCATTERED RADIATION FROM AN ELECTRON LINEAR ACCELERATOR*

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## ABSTRACT

A tungsten moderator will be placed behind the target of the Oak Ridge Electron Linear Accelerator (ORELA) to convert gamma radiation to slow positrons. These will be extracted and led through evacuated solenoids to an experiment room. A Penning trap will be used to extend the slow positron pulses to achieve duty factors of 10% or greater. The facility will be used for atomic and molecular physics studies, positron microscopy, and materials research. Operations will be inexpensive and will not interfere with the normal function of ORELA, the measurement of neutron cross sections by flight-time spectrometry.

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## INTRODUCTION

In recent years there have been many demonstrations of the potential usefulness of slow positron spectroscopy for materials analysis and atomic and molecular physics studies. High intensity slow positron facilities are needed to allow these new areas of science to proceed. Brookhaven National Laboratory has constructed a based around the production of $^{64}$Cu with a nuclear reactor (1), yielding currents of 5 x $10^7$ slow positrons per second. At Lawrence Livermore National Laboratory (2), University of Mainz (3), and at University of Tokyo (4) electron linear accelerators (LINAC) have been used in conjunction with tungsten moderators to produce average beam currents as high as 1 x $10^9$ slow positrons per second. In this paper we describe an extension of the LINAC technique that has innovations to simplify operation, increase duty factors, and decrease operation expense.

## A DESIGN FOR EXTRACTION-STORAGE-DISPENSING OF SLOW POSITRONS FROM A PULSED LINAC

Figure 1 shows the general layout of the slow positron facility presently under construction for use at the Oak Ridge Electron Linear Accelerator (ORELA). The ORELA operates in a pulsed mode with repetition rates ranging from 30-1000 hz. Pulse widths vary from 2-30 ns, maximum energy of the incoming electrons is 180 MeV. The beam is impacted on a water-cooled tantalum target, producing intense bursts of bremsstrahlung that photoeject neutrons. The dashed lines in Figure 1 indicate neutron flight tubes. One of the tubes has been modified for installation of a positron beam line. There will be no interference with any of the other neutron flight paths. The ORELA will be able to supply both positrons and neutrons simultaneously.

Positrons and electrons resulting from bremsstrahlung pair production in the tantalum target are forward scattered. Calculations indicate that the lower energy positrons are annihilated as they pass through the target cooling water, and that most of the radiation entering the moderator of the slow positron apparatus is in the form of photons. The tungsten moderator will convert the photons to slow positrons by a mechanism explained in the following section. The slow positrons will be accelerated down an evacuated flight path, around which solenoids are placed to produce an axial magnetic field of approximately 100 gauss. They will assume spiral trajectories whose centers follow the flight path axis. This type of solenoidal conduction is capable of guiding the beam around gentle curves.

Inset (a) in Figure 1 schematically illustrates the target room extraction solenoid. It consists of two concentric aluminum tubes joined together on the outside of the room, the inner tube extends to within 1-2 cm of the moderator but does not make contact with it. On the outside of the target room a large ferrite toroid is placed between the inner and outer tubes, forming an inductive load for the negative voltage pulses which travel to the open end of the inner tube facing the moderator. The negative potential will extract the positrons into the tube. The extraction pulse will be synchronized with the accelerator cycle and will not be lowered to ground until after all the positrons have entered the extraction tube. Thus, throughout the rest of their flight the positrons will retain the kinetic energy imparted to them by the pulse. Preliminary electronic tests show that it will be possible to impart to the positrons as much as 10 keV with variations of no more than 5%. The positrons will exit from the extraction tube and travel through a solenoid to the Penning trap located in the experiment room.

Inset (b) of Figure 1 schematically illustrates the Penning trap. The solenoid of the Penning trap has been constructed according to the design of Malmberg and coworkers (5). It is 183 cm in length, 34 cm mean diameter, wound on a water-cooled aluminum core, producing fields of 300-500 gauss which will radially contain the positrons. They will be contained longitudinally in a 1-meter drift tube placed in the center of the solenoid by charged cylinders at each end. When the positron burst reaches the Penning trap the potential of the entrance cylinder will be dropped to allow admission into the drift tube, whose potential will have been set to decelerate the positrons to a round-trip flight time greater than 100 ns. In the time required for the burst to return to the entrance cylinder its potential will have been reset for trapping. Time lapses between slow positron bursts will vary 1-33 milliseconds, depending on the accelerator repetition rate. During this dead period the potential of the drift tube will be raised so that the positrons can overcome the barrier of the exit tube and escape from the trap. Thus, the Penning trap will extend the time frame over which positrons are dispensed, making single particle counting much easier. The potential of the exit lens will be adjustable so that positrons with energies as high as 20 KeV can be supplied. Preliminary tests show that the potential of the entrance tube can be restored in times less than 50 ns, which is sufficient to achieve trapping. The magnetic field must restrain the positrons from colliding with the walls of the drift tube as they undergo the many thousands of reversals in their flight direction. Malmberg and coworkers (6) have demonstrated that electron clouds can be restrained from wall collisions for times in excess of 5 minutes. Our required containment times will be factors of 1000 less than this.

The brightness enhancement devices ("B" in Figure 1) allow the positron beam to be adjusted to a very small energy spread, $< 0.2$ eV, and also to be collimated for high precision spectroscopy measurements and other applications such as microprobe and microscope techniques.

## ESTIMATION OF SLOW POSITRON YIELD

The tungsten and molybdenum moderators were first developed by the authors (7,8,9), using radioisotope sources. Both of these metals have large negative work functions for positrons, which contribute to their efficiency. Experiments at LLNL (10) by Howell et al. showed that the tungsten moderation efficiency is disproportionately higher than that of molybdenum for positrons produced by a LINAC source. The high atomic number of tungsten contributes to the generation of fast positrons by pair production, resulting in more slow positrons.

Calculations have been made of the fast positron content of the ORELA beam as it proceeds through the tantalum target and the coolant water behind and enters the tungsten moderator. Inset (c), Figure 1, shows a calculation of the fast positron spectrum that will result from pair formation in the moderator. The spectrum is differentially distributed with units that represent the fraction of fast positrons produced per accelerator electron that strikes the tantalum target. The calculations for Figure 1(c) were made with the EGS program (11). It is unfortunate that the calculations are statistically unreliable for energies below 0.4 MeV, positrons of lower energies are the more likely to be thermalized and retrieved from moderators. Slow positron yields for radioisotope sources, most of which emit fast positrons with energies less than 650 keV, can be estimated by multiplying their total emissions by factors ranging from $10^{-4}$ to $10^{-3}$. Applying the $10^{-4}$ factor to the integral of the spectrum in Figure 1(c) over the range of 0.4-1.0 MeV, and multiplying by the average current of the ORELA, 1.7 x $10^{15}$ electrons per second, a current of 1.2 x $10^{8}$ slow positrons per second is predicted.

As another approach to estimating slow positron yields, we will consider fast positron production in the tantalum target, which should correspond to the gamma-positron converter configuration of the LLNL group. The total integral of the tantalum target spectrum predicted a fast positron yield of 0.33 per accelerator electron. The LLNL group reported a slow positron yield of about 1 x $10^{-6}$ per accelerator electron (2). Using the ratio of these two yields, we calculate that the fast positron-slow positron moderation efficiency is 3 x $10^{-6}$ for LINAC-based facilities. The integral of the spectrum in Figure 1(c) is 0.024, which represents the total yield of fast positrons produced in the moderator per incident electron. Multiplying this quantity by the calculated moderation efficiency and by the average ORELA current, we again arrive at a slow positron output of 1.2 x $10^{8}$ per second.

The exact agreement between the yields estimated by the above two methods is undoubtedly fortuitous, but we are encouraged that they are of the same magnitude. If we assume a factor of 10 for the unforeseen inefficiencies in moderation and transmission for our facility, we conclude that we should be able to deliver at least 1 x $10^{7}$ slow positrons per second. It will be possible to adjust the ORELA beam so that it will strike the moderator directly and generate positron outputs that will be much more intense. This will decrease neutron output, however, so this mode of operation will be used only for those experiments whose budgets can afford to pay for accelerator time.

## APPLICATIONS OF SLOW POSITRON BEAMS

Dale et al. (9) and Mills (12) have discussed the use of slow positrons for studies of solid surfaces. Examples of atomic and molecular physics studies can be found in work by Kauppilla and Stein (13). The most immediate atomic and molecular physics work that the authors plan for this facility involves collaboration with their colleagues, Donohue, Young, Glish, McLuckey (14), in their suggestions for measuring cross sections of positron interactions with ions and rydberg atoms, for studying stimulated ion desorption with positrons, and for using positrons to create ions in analytical mass spectroscopy measurements. Dale et al. have discussed some of the aspects and advantages of high energy positron diffraction (9). Weiss et al. have discussed the advantages of low energy positron diffraction (15). Good angular resolution in diffraction measurements requires the use of brightness enhancement methods, first suggested by Mills and Canter (16): The positron beam is condensed on the surface of a moderator, thermalization inside greatly reduces lateral components of momentum. About 30% of the positrons diffuse back to the moderator surface and the negative work function causes re-emission with a predominance of forward momentum. The total number of retrieved positrons decreases, but the angular spread and cross section of the beam is reduced, effecting a significantly increased brightness. The brightness enhancement devices indicated in Figure 1 will be of the reflection type used by Frieze et al. (17).

It should be possible to use brightness enhancement to devise a positron microscopy method. In Figure 2 we indicate the condensation of a positron beam on the back of a thin moderator film. The positrons diffuse to the front of the film and are re-emitted; the emission spot is imaged on a microchannel plate. This technique is reminiscent of the field electron emission microscopy methods, but it will have the advantage that no field will be necessary to extract the positrons. The negative work function of the moderator will cause them to be emitted spontaneously. Thus, the extremely high extraction fields, which destroy samples used in the electron method, will not be necessary. Positron emission microscopy should be useful for studying adsorbates on moderator surfaces and for imaging large molecules. Since low energy positrons are involved, contrast should be determined by the chemical nature of the object being imaged. Hulett et al. have calculated that real magnifications as high as 10,000 can be achieved (18).

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## FIGURE CAPTIONS

Figure 1. Slow positron facility to be installed at ORELA. T-Target, M-Moderator, P-pulser, PT-Penning trap. B-brightness enhancement. S-spectrometry. Shaded areas indicate concrete radiation shielding.

Figure 1(a). Pulsed extraction tube. Hatched portion indicates ferrite toroid.

Figure 1(b). Penning trap

Figure 1(c). Spectrum of fast positrons produced in moderator.

Figure 2. Scheme for positron emission microscope.

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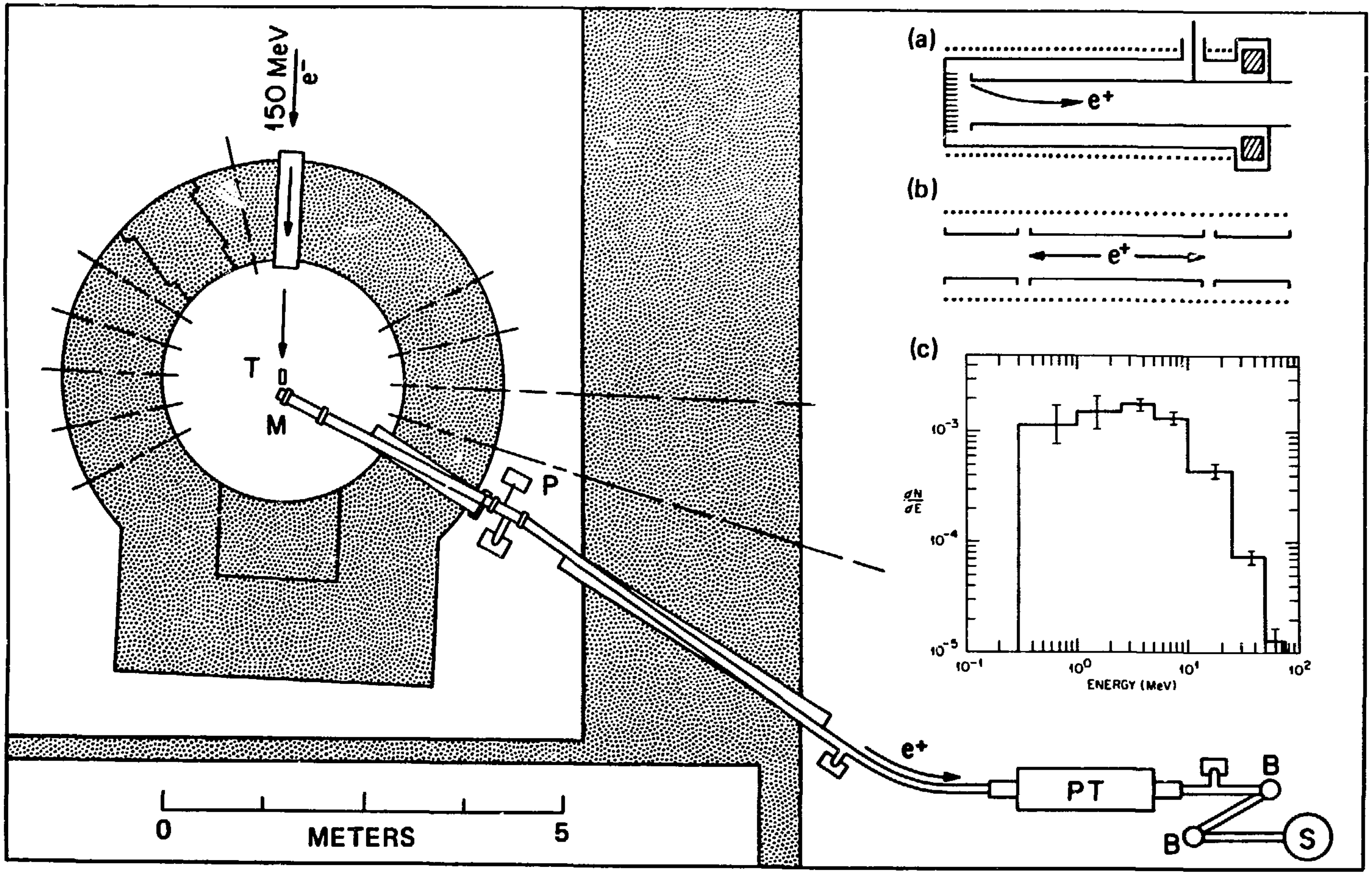

Fig. 1
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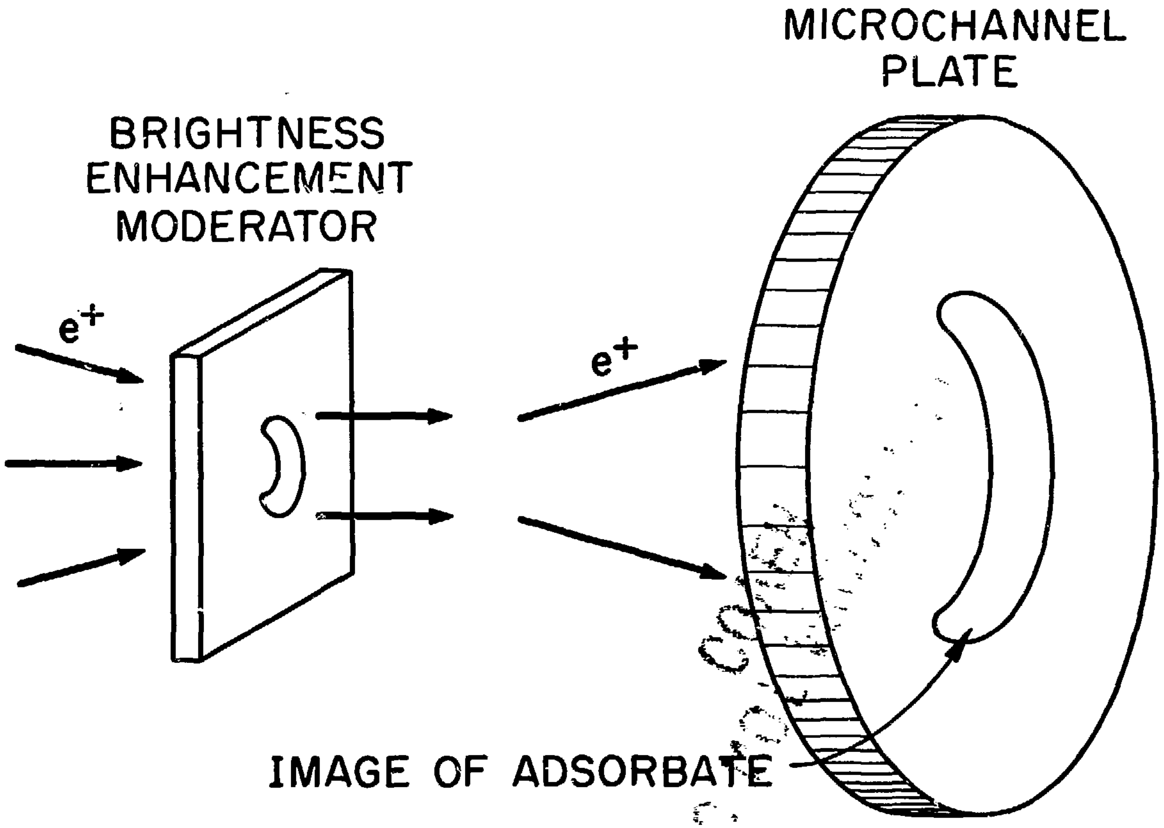

Fig. 2
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