CONF-830770--3

BNL--33534

BNL-33534

DE83 017580

INTENSE POSITRON BEAMS AND POSSIBLE EXPERIMENTS

K. G. Lynn and W. E. Frieze

Physics Department, Brookhaven National Laboratory

Upton, New York 11973 U.S.A.

July 1983

The submitted manuscript has been authored under contract DE-AC02-76CH00016 with the Division of Basic Energy Sciences, U.S. Department of Energy. Accordingly, the U.S. Government retains a nonexclusive, royalty-free license to publish or reproduce the published form of this contribution, or allow others to do so, for U.S. Government purposes.

Intense Positron Beams and Possible Experiments

K. G. Lynn and W. E. Frieze

Physics Department, Brookhaven National Laboratory

Upton, New York 11973 U.S.A.

INTRODUCTION

In this paper, we will survey some of the ideas that have been proposed regarding the production of intense beams of low energy positrons. Various facilities to produce beams of this type are already under design or construction and other methods beyond those in use have been previously discussed.(1) Moreover, a variety of potential experiments utilizing intense positron beams have been suggested. It is to be hoped that this paper can serve as a useful summary of some of the current ideas, as well as a stimulation for new ideas to be forthcoming at the workshop.

We begin with a general description of the development of variable energy positron beams to date. A second section will emphasize the intense positron beams currently being built. Particular advantages and disadvantages will be discussed for the methods to be used to produce positrons for these beams. Emphasis will be placed on the beam under construction at the High Flux Beam Reactor (HFBR) at Brookhaven. The third section of the paper will briefly sketch some of the new condensed matter experiments that will be possible in the future owing to the increased positron current. Some of these proposed experiments are feasible immediately, while others must await implementation of certain technological developments (such as brightness enhancement) (2) for their completion.

PRESENT BEAMS

We make the distinction in this paper between laboratory based beams, which are completely self-contained and utilize a dedicated positron source, and facility based beams, which utilize an accelerator or reactor to provide an intense source of positrons. Slow positron experiments have thus far been done almost exclusively using laboratory based beams in which the number of particles varies from 10^4 to $5x10^6$ per sec. This current of positrons is suitable for a large class of experiments as is demonstrated by the many measurements that have been done using them already (1,3). Some measurements however, do require higher positron rates and for these the new, intense beams are necessary.

Operationally, we will define intense positron beams as those that will supply more positrons than any presently existing laboratory beam using standard radioactive isotope sources (i.e. Co^{58}, B^{11} and Na^{22}). This definition is not strictly correct as sometimes facility based beams can have characteristics such as time bunching which can make them ideally suited for certain experiments even though the average current may be less than a standard laboratory beam.

The beams presently in use can be classified based on the source of the positrons, the type of moderator employed, and the transport system used, i.e. magnetic or electrostatic. In this paper we will not discuss general moderator development. Suffice it to say that low defect density polycrystalline (4) or single crystal (5) W samples appear to yield the largest moderation efficiencies as of this writing. Some recent experiments at Brookhaven seem to indicate that Pt(100) + CO (6) may also be competitive with single crystal W.

The type of transport system chosen will be dependent on the experiments planned. However, experience at Brookhaven has shown that systems using transport by a magnetic guiding field are much easier to construct and operate. (7) In this technique one uses an axial magnetic field to guide the positrons, caught in small cyclotron orbits, out of the high background source region and into a target chamber. Building a fully electrostatic beam is more complicated but allows more versatility; in these systems, electrostatic lenses of various types are used to focus and transport the extracted slow positrons. In the future, hybrid beams are likely to be developed where the moderated positrons will be magnetically transported into an electrostatic final section promising a compromise between ease and flexibility.

The source of positrons most commonly used is a commercially purified source, e.g. Co^{58}, which is plated onto a metal backing (8) or a salt of Na^{22} which is housed in a vacuum capsule or is incorporated into some medium such as glass or ceramic. These commercially purified sources are usually limited in total activity (<50mCi of positrons) and are rather expensive. Another source which has been utilized successfully is produced when protons(9) are used to irradiate a B^{10} target. Positrons are then emitted from C^{11} produced by the irradiation. A tabulation of all those positron sources which have a half-life greater than 12 hours is shown in Table 1, listed in order of the relative fraction of β^+ per disintegration.(10)

INTENSE POSITRON BEAMS

The production of intense positron beams ($\geq 5 \times 10^6$ positrons per sec) will probably require techniques not available in the laboratory. While many methods can be imagined which will produce large numbers of positrons, facility based beams using two different methods are currently being constructed. These two methods utilize either a linear electron accelerator (11,12,13) to produce electron-positron showers via pair production or a nuclear reactor to produce intense Cu^{64} sources by neutron capture.

In the first method, one generates an intense positron beam by moderating the positrons produced in the positron-electron showers created by the incident electron beam. (11) This method may prove to produce the largest total number of slow positrons of any method that has been suggested. Efficiencies between 10^{-6} and 10^{-4} positrons per incident electron have been reported under conditions of reduced primary beam intensity (11,12). Whether these efficiencies can be maintained as the beam intensity is increased remains to be demonstrated. In the case of increased electron beam intensity, considerable radiation damage and heating of the target occurs, both of which effects are known to reduce the efficiency moderation (1). If these problems can be solved, however, a linac such as that at Livermore National Laboratory might conceivably yield as many as 10^{11} positrons per sec, a rate obtainable in reactor based beams only with sources in the 10 kCi range.

Beam rates as large as this may make linac based slow positron beams quite useful for certain experiments, but a number of disadvantages are also present. Perhaps the primary one is cost. Because a linac beam requires the full electron beam for maximum positron flux, simultaneous operation with other users is impossible. If one is familiar with the scheduling and other problems involved in accelerator use, the difficulty involved here is apparent (especially when coupled to experiments involving the chemistry or physics of surfaces where considerable sample preparation time is required while positrons are also available).

Another aspect of linac beams may be an advantage or a disadvantage, depending of the application. Because many of these machines are intrinsically time pulsed in nature, experiments which require a start signal when a positron arrives are simplified. However, other experiments will be much more difficult due to the very low duty cycle of these pulsed beams. Except for the detection efficiency measurements, the presence of thousands or even millions of positrons within a few tens or hundreds of ns will cause serious problems with accidentals.

Certain other linac characteristics are probably of less significance, but deserve mentioning. Because of long lived isotopes produced by the primary beam, access to the moderator will be very limited, thus making changes, maintenance or repair more difficult. A related problem is that transport of the positron beam out of the shielded target room is a fairly difficult and expensive operation. This will also cause time debunching due to the length of required, and thus, some of the advantages of a pulsed machine may be lost. Finally we note in passing that linac beams are intrinsically unpolarized, a situation which may or may not be a drawback.

We see then that linac based beams have a promising future although a variety of problems need to be solved. Still, if the primary problem, that of maintaining moderation efficiency as the primary beam intensity is increased, can be solved then it is certain that these beams will be major contributors to the future of slow positron physics.

A second method of producing copious amounts of positrons is to produce the Cu^{64} isotope. This is done by thermal neutron capture by Cu^{63} in a nuclear reactor. A fortuitous aspect of this method is that Cu^{64} has a short half-life (12.7h) and low background of gamma rays. This first characteristic reduces any problems due to long term contamination of an experimental apparatus. Using the thermal neutron capture cross section for Cu^{63} of 4.5 b and, for example, using the thermal neutron flux of $1x10^{15} n/cm^2$-sec available at the HFBR, we obtain an activity of 580 Ci per gram of natural Cu after a 24 hr. irradiation. A 1 cm^2 source with a thickness corresponding to the beta end point range in Cu of 0.023 cm, would give an activity of 120 Ci, more than two orders of magnitude larger in positron activity than the 0.2-0.5 Ci ^{58}Co sources used in many slow positron beams.

Taking an effective moderation efficiency of $1x10^{-3}$ and beam transmission of 90% (and including a branching ratio of 19% for e^+ decay) we obtain a beam rate of $4x10^8$ s^{-1} for a 1 cm^2 source, around 100 times the rates measured in existing beams. As the result of the 12.7 h half-life, the total number of slow positrons available per non-enriched Cu source is $2.5x10^{13}$.

This type of reactor based beam is ideally suited for continuous beam operation as no intrinsic time structure is present. However, one is not limited to this type of experiment. For example, on the laboratory based electrostatic beam at Brookhaven we have found that timing resolutions on the order of 600 psec full width at half maximum (FWHM) can be obtained by simply using the secondary electrons generated when positrons strike a target as a start signal and the annihilation gamma ray as the stop signal. (14,15) The secondary electrons were detected by a Channel Electron Multiplier Array and the annihilation photons by a BaF_2 scintillator crystal. This shows that one can do high resolution timing experiments on an unbunched beam.

The reactor method of production also allows for the capability of making highly spin polarized positron beams simply by using a transmission type self-moderator thus increasing the ratio of v/c in those positrons which become moderated. Such a moderator could be produced by evaporating various amounts of non-radioactive Cu as overlayer. This characteristic of producing a highly polarized as well as intense beam opens makes feasible many new experiments. For example, one can perform an energy and angle resolved measurement of emitted Ps (16,17) from ferromagnets. This would provide more information on the nature of the electrons involved in surface magnetism.(15)

A major advantage of a reactor based beam is that one can run in a truly symbiotic mode and not have a measurable effect on other reactor operations. This procedure also allows for a number of simultaneous irradiations of different Cu^{63} samples to feed a number of potential beams. Owing to the short half-life of Cu^{64} and the intensity of the emitted radiation, all such beams must, however, be very close to the irradiation ports of the reactor. The cost per irradiation is relatively small in an operating reactor. One does need a large thermal flux to make the specific activity of the Cu source adequate to produce an intense moderated positron beam. One should also note that there are fewer research reactors than available linac's in the world thus limiting this approach to a small number of institutions.

The initial reactor based beam being constructed at Brookhaven is a simple magnetic transport design similar to several existing beams. The positrons will be transported at energies of up to 5 keV using a field of 50-100 Gauss with two $\vec{E}x\vec{B}$ filters (8) to remove any straight line path in the beam, thereby shielding from gamma rays and unmoderated positrons (see Fig. 1).

The Brookhaven system will use an evaporated single crystal Cu source. Owing to the short half-life of Cu^{64} one needs to transfer the irradiated source every few days thus requiring a remotely controlled source preparation chamber. The source chamber is housed in a concrete shielding house which provides adequate shielding for up to 10kCi of Cu^{64}. After irradiation of the Cu sphere it isremoved from the reactor and transferred through an airlock system into an evaporation crucible (Figure 2).

A fortuitous property of Cu(111) is that in single crystal form it has been shown to be a very effective positron moderator; therefore, the positron source will be used as its own moderator as well. Those positrons emitted from the Cu^{64} atoms in the bulk of the source/moderator which stop within a few diffusion lengths of the surface (≈1100 Angstroms for Cu) will escape the solid with some energy ranging up to the positron work function (0.6 eV). This self-moderating source can be made by evaporating the irradiated Cu directly onto a W substrate in our source chamber.

It has been found in various measurements that one can grow Cu(111) epitaxially on W(110). Studies have been performed at Brookhaven even at high evaporation rates with good LEED patterns being observed. This indicates that the hybrid W/Cu(111) system should be very effective as a defect free moderator. After the source has decayed one can evaporate another Cu source on top or simply evaporate the Cu off of the W substrate by heating it to high temperatures.

PROPOSED EXPERIMENTS

As we have mentioned, a variety of experiments have been proposed which would benefit from the fluxes available on one of these new machines. One such experiment currently under active consideration at Brookhaven is a study of the reflection of positronium (Ps) atoms from well-characterized solid surfaces.(18) This would provide us not only with a better understanding of Ps-surface interaction but also clarify the possibility of producing beams of positronium atoms for use in the study of surfaces and in particular the possibility of observing Ps diffraction. This subject has been discussed in detail in K. Canter's contribution to this workshop. In the beam proposed at the HFBR one would expect to be able to measure reflection coefficients down to $R=10^{-4}$, using a simple technique. (If Ps generates secondary electrons when impacting a surface this would increase the efficiency of detecting Ps by more than an order of magnitude over a simple annihilation technique, thereby extending our expected sensitivity even further.)

A second experiment planned is to combine the technique of angular correlation of annihilation radiation(19) with the intense slow positron beam.(18) This would provide the first momentum density information about surface electrons sampled positrons bound in the surface states found on most metals. Such an experiment should provide unique information on the momentum density of electrons at surfaces. An additional result would be to probe many-body correlations on the surface. This is undoubtably different from that in the bulk due to the large electric field which is produced by the surface dipole. The first experiments will focus on the simple metals which only have s and p electrons, in order to more fully estimate and understand these many-body effects. Finally, one could obtain a measurement of the velocity distribution of emitted Ps by observing the angular correlation signal of para-Ps atoms which decay very near the surface. This measurement should provide information regarding the density of electron states at the surface, microscopic roughness, overlayers and adsorbates, and many related phenomena.(20)

Other experiments will require the implementation of brightness enhancement of the positron beam such as proposed by Mills(2). By utilizing this technique one could make a beam with high spatial and energy resolution using a series of reflection or transmission moderators. (See A. Mills contribution in this workshop.) Being somewhat optimistic on these developments one should be able to reduce the beam diameter by a factor of 50 with about one-third to one-tenth of the positrons remaining after each stage of remoderation. A rough estimate with our beam ($4x10^8 e^+$/sec) yields a reduction to ≈1000Å diameter in as few as three stages with approximately 2% or 10^6-10^7 e^+/sec remaining. Another way of using brightness enhancement would be to reduce the beam diameter obtained from a relatively large area radioactive source. In the case of our HFBR beam, a source of 10 cm diameter could yield an increase of the beam of positrons to $4x10^{10}$ e^+/sec or a current of 6nA of slow positrons.

With positron currents in the nA range one can consider many new types of experiments. For example, one could produce a low voltage, high spatial resolution (≈1000Å) and easily sweepable positron beam. This would allow one to build a scanning positron microscope/microprobe.(1) Such a device would be a unique probe for studying surface and near surface defects, i.e., dislocations, vacancies and their clusters, grain boundaries and small particles. One could not only measure the reflected or transmitted incident beam as in conventional electron microscopes, but in addition, such unique positron characteristics as the energy and angle of the re-emitted Ps and positrons, and the timing, energy and angle of the annihilation radiations could all be used as signals.

One could for example use this high-resolution feature coupled with the new measurement of re-emitted positron energy loss spectroscopy(21) to detect whether adsorbed molecules have specific adsorption sites such as at steps or defects at the surface. This information would be very useful in the field of catabysis.

Another example would be to couple existing techniques such as positron lifetime or angular correlation measurements with the microbeam. The small spot size coupled with a variable beam energy might permit measurement of such characteristics as defect concentration as a function of spatial position on a sample. At Brookhaven a higher energy (0-100 keV), poorer spatial resolution (5 mm) beam has been constructed and has shown that one can detect defects in semiconductors caused by ion implantation. Triftshauser and Kogel (22) has seen defects in irradiated metals and are presently coupling their slow positron beam to an ion implantation machine to perform sequential experiments studying the damage created during implantation.

Another potential use for positrons, either in normal or brightness enhanced beams is to remove individual electrons from a sample. Because neither thermalized positrons nor annihilation gamma rays strongly interact with the atoms in a solid, one can view them as a means for abrupt removal of a single electron from its surroundings with a minimum of other disturbance (i.e. no initial or final state complications). One can imagine a number of studies of solids or perhaps of atomic and molecular species in which this would be quite useful. A possibility might be "positron simulated desorption" of adsorbed gas ions. Here positrons should be quite valuable in determining the detailed mechanism by which electron or photon stimulated desorption proceeds(23). A potential benefit in the case of removing electrons in this way is that the electron momentum might well be measureable using the annihilation radiation, thereby even allowing one to be specific as to which electrons have been removed.(24)

A easy measurement one could make using a high flux beam would be to study the time dependence of certain phenomena on a sub-millisecond scale. By measuring the current to a sample under positron irradiation, the number of positrons leaving by re-emission can be determined. By measuring the number of annihilations near the sample in the traditional way one can determine the number of positrons leaving by re-emission or Ps formation. In either case, the use of a high flux beam permits relatively accurate measurements of fast, one-time phenomena. Accuracies of a few percent for a time interval of a few tenths of a millisecond should be possible with rates in the 10^8-10^9 s^{-1} range. One suggestion might be to study the motion of defects near the crack tip in the case of crack propagation. A small diameter, sweepable beam would be an obvious advantage in this case. One could also consider studying surface chemical reactions on this time scale.(25)

Another possibility is to detect positron channeling and to use it as a means of impurity lattice location. For example owing to the positive charge the positron will tend to stay in the channels between the ion cores. If an impurity is located in the channel the positron will be obstructed, thus producing a characteristic blocking pattern or induced impurity x-ray. Positron channeling, in comparison with microbeam proton channeling, gives increased yield and reduced sample damage.

It should be stressed that the complexities imposed by the accelerator or reactor on the experimentor are considerable. When these constraints are coupled with the already complex techniques of the laboratory positron beam, the project becomes extremely formidable. We would suggest that no one embark on the construction of a facility based intense beam without first mastering the techniques of building a laboratory based beam system. This should not disuade anyone, for one should realize that there is a wealth of new condensed matter experiments that can be performed on a laboratory beam. For example, one study has been made on insulating systems and the results are quite surprising and interesting(26). This measurement has shed new light on the formation mechanism of Ps and Ps trapping at defects, and given a value for the Ps diffusion coefficient in a molecular solid. No work has yet been done on positron diffusion in liquid metals or during melting. Preliminary results on the positron diffusion length in semiconductors are very surprising and at the time of this writing not well understood.(27)

Very little work has been performed on submonolayer or monolayer overlayers on metal substrates.(28) Quantitative comparisons between the changes in electron and positron work functions in these and other systems are needed to clarify the degree to which these are correlated. Only a few positron work functions have been measured even on clean metal systems (1,29).

Only two preliminary studies have been performed on low energy positron diffraction (30,31) and much work is needed in this area. The spatial dimensions of the positron beam are important to diffraction studies and brightness enhancement would be useful in developing this potentially useful technique.

New work is only now being attempted in measuring the decay rates of positrons associated with the surface of a clean metal. Changes in this lifetime spectra in Al have been detected by changing the surface either by damage or adsorption of an impurity.(14) These positron surface lifetime studies will provide much needed information in unraveling the large amounts of data acquired in bulk positron annihilation studies of voids (internal surfaces) in metals. These voids are generated by neutron irradiation or electron irradiation so that impurities on their surfaces can only be controlled in a very indirect manner(32).

It would be straightforward using a beam to measure the vacancy formation enthalpies of the high melting point metals. Using both Ps and positron re-emission one can make these measurements(1) very rapidly compared to bulk methods. Moreover, bulk techniques themselves can also be performed on a high energy beam as we have mentioned (33).

Very little work has been attempted on measuring the backscattering fraction of low energy positrons (0-100 keV) on various materials. In fact only a minimal amount of work has been performed on the details of positron energy loss in comparison with electron energy loss in adsorbed overlayers.

New studies utilizing the spin polarization of positrons have been made to measure surface magnetism at various temperatures on a pure metal.(15) Hopefully this work will be continued into thin overlayer systems. These spin polarization studies could also be used for studies in atomic physics such as positron-atom, Ps-atom and Ps-electron scattering.

As one might imagine this list is far from exhaustive. However it is to be hoped that it might leave the reader with the realization that there is a large number of experiments to be performed both on laboratory beams and on intense beams. We also hope that other researchers will continue to consider new uses of positron beams in the future in many areas of pure and applied physics, chemistry and materials science.

ACKNOWLEDGEMENTS

The authors wish to thank H. Lutz for making valuable comments ou an earlier version of this paper as well as A. P. Mills and P. J. Schultz for useful discussions. Work performed at Brookhaven National Laboratory is supported by the Division of Materials Sciences, U.S. Department of Energy, under contract DE-AC02-76CH00016.

REFERENCES

1. A. P. Mills Jr., Comments on Solid State Phys. 10, 173 (1983); Positron Solid State Physics, Proceedings of the 83rd Session of the International Summer School "Enrico Fermi" at Vanenna, Italy, 1981, W. Brandt and A. Dupasquier, eds. (Plenum, N.Y., 1983) - See contributions of K. G. Lynn and A. P. Mills, Jr.

2. A. P. Mills Jr., Appl. Phys. 23, 189 (1980).

3. A. P. Mills Jr., Science 218, 335 (1982).

4. L. D. Hulett, J. M. Dale and S. Pendyala, Surf. and Interface Analysis 2, 204 (1980).

5. A. Vehanen, K. G. Lynn, P. J. Schultz and M. Eldrup, to be published Appl. Physics.

6. H. Jorch, T. E. Jackman, P. J. Schultz and K. G. Lynn, unpublished data.

7. K. G. Lynn and H. Lutz, Rev. Sci. Instrum. 51, 7 (1980).

8. A. P. Mills Jr., Appl. Phys. Letts. 35, 427 (1979).

9. T. S. Stein, W. E. Kauppila and L. O. Roellig, Rev. Sci. Instru. 45, 951 (1974).

10. J. S. Greenberg and E. D. Theriot, Jr., Vol. IVA, Methods in Experimental Physics, Eds. V. W. Hughes and H. L. Schultz.

11. R. H. Howell, R. A. Alverez, K. A. Woodle, S. Dhawan, P. O. Egan, V. H. Hughes, M. W. Ritter, Seventh Conf. on the Application of Accelerators in Research and Industry, North Texas State University, Denton, Tx. (1982).

12. G. Gräff, R. Ley, A. Osipowicz and G. Werth, this workshop.

13. M. Begemann, G. Gräff, H. Herminghaus, H. Kalinowsky and R. Ley, to be published in Nucl. Instr. and Methods.

14. K. G. Lynn, W. E. Frieze and P. Schultz to be published.

15. D. W. Gidley, A. R. Koymen and T. W. Capehart, Phys. Rev. Lett. 49, 1779 (1982).

16. A. P. Mills, Jr., L. Pfeiffer and P. M. Platzman, to be published.

17. Peter J. Schultz, K. G. Lynn, and W. E. Frieze, to be published.

18. This experiment has been proposed with a consortium of researchers which include L. Roellig, S. Berko, K. Canter, A. P. Mills, Jr., W. E. Frieze and K. G. Lynn.

19. See review by S. Berko in Ref. 1.

20. A similar experiment is also being attempted by the Livermore Group on their LINAC based beam - private communication, R. Howell.

21. D. A. Fischer, K. G. Lynn and W. E. Frieze, Phys. Rev. Letts. 50, 1149 (1983).

22. W. Triftshauser and G. Kogel, Phys. Rev. Letts. 48, 1741 (1982).

23. M. L. Knotek, V. O. Jones and Victor Rehn, Phys. Rev. Letts. 43, 300 (1979).

24. K. G. Lynn, J. R. MacDonald, R. A. Boie, L. C. Feldman, J. D. Gabbe, M. F. Robbins, E. Bonderup, and J. Golouchenko, Phys. Rev. Letts. 38, 241 (1977).

25. R. J. Wilson, private commmunication.

26. M. Eldrup, A. Vehanen, P. J. Schultz, and K. G. Lynn, to be published.

27. H. Jorch, K. G. Lynn and I. K. MacKenzie, Phys. Rev. Letts. 47, 362 (1981).

28. P. J. Schultz, K. G. Lynn, W. E. Frieze, and A. Vehanen, Phys. Rev. 1327, 6626 (1983); K. G. Lynn, Phys. Rev. Letts. 44, 1330 (1980); D Gidlay, private communication.

29. C. A. Murray, A. P. Mills, Jr. and J. E. Rowe, Surf. Sci. 100, 647 (1980).

30. I. J. Rosenberg, A. H. Weiss, and K. F. Canter, Phys. Rev. Lett. 44, 1139 (1980).

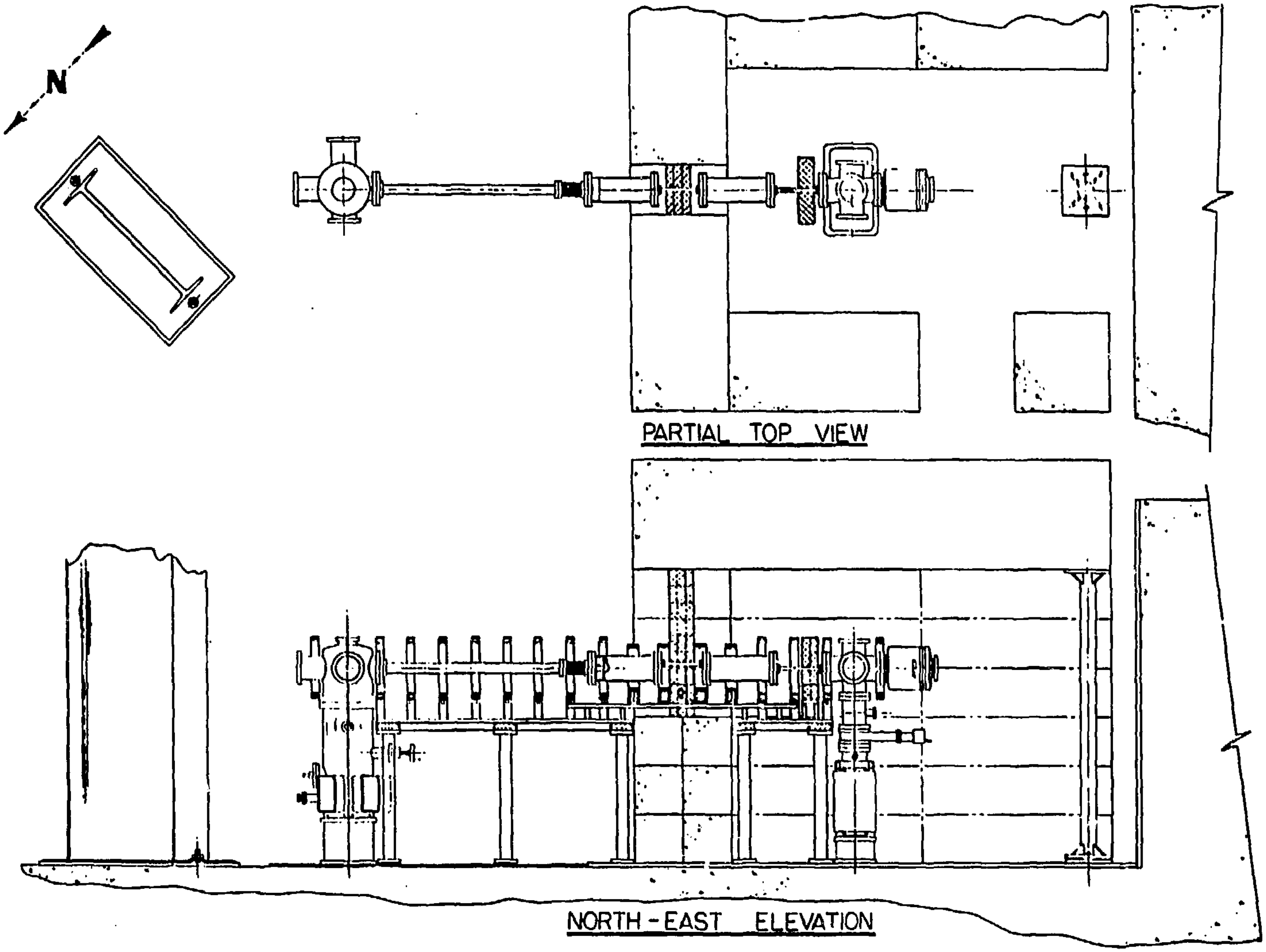
31. A. P. Mills, Jr. and P. M. Platzmann, Solid State Comm., 34, 541 (1980).

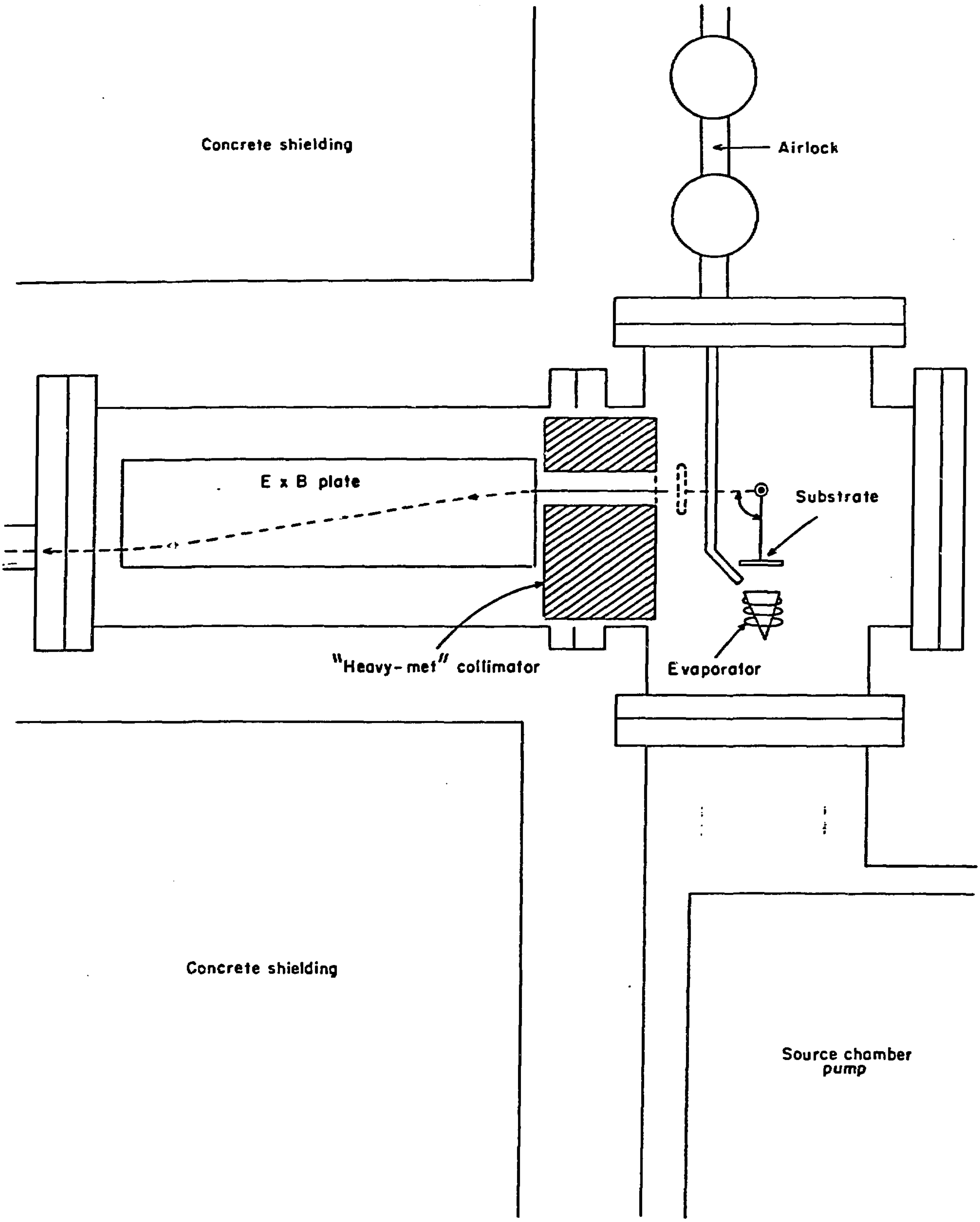
32. Positron Annihilation, Proceedings of the 6th Int. Conf. at Arlington, Texas, P. Coleman, S. Sharma, L. Diana, eds. (Plenum, N.Y. 1982).

33. P. J. Schultz and K. G. Lynn, to be published.

Table 1: Suitable Positron-Emitting Isotopes

Isotope	τ	β^+/dis	β^+	Production Reaction
Na^{22}	2.6y	0.89	0.54	$Mg^{24}(d,\alpha)$
Al^{26}	7.4×10^5y	0.85	1.17	$Mg^{24}(d,\gamma)$
Co^{55}	18.2h	0.60	1.50,1.03,0.53,0.26	$Fe^{12}(p,2n)$
V^{48}	16.2d	0.56	0.69	$Ti^{48}(p,n)$
Ni^{57}	36h	0.50	0.85,0.72,0.35	$Ni^{58}(p,pn)$
Sr^{83}	33h	0.50	1.15	$Sr^{84}(p,pn)$
Y^{86}	14.6h	0.50	1.80,1.19	$Sr^{86}(p,n)$
Br^{76}	17.2h	0.44	3.57,1.7,1.1,0.8,0.6	$Se^{76}(p,n)$
Nb^{90}	14.6h	0.40	1.51,0.66	$Zr^{90}(p,n)$
Mn^{52}	5.7d	0.35	0.58	$Cr^{52}(p,n)$
Ge^{69}	40h	0.33	1.22,0.61,0.22	$Ga^{69}(p,n)$
As^{71}	62h	0.30	0.81	$Ge^{72}(p,2n)$
As^{72}	26h	0.30	3.34,2.50,1.84,0.67,0.27	$Ge^{72}(p,n)$
I^{124}	4.5d	0.30	2.20,1.50,0.70	$Te^{124}(p,n)$
As^{74}	17.5d	0.29	1.53,0.92	$Ge^{74}(p,n)$
Zr^{89}	79h	0.25	0.91	$Y^{89}(p,n)$
Co^{56}	77d	0.20	0.44,1.50	$Fe^{56}(p,n)$
Cu^{64}	12.8h	0.19	0.65	$Cu^{63}(n,\gamma)$
Rb^{84}	33d	0.17	1.63,0.82	$Sr^{86}(d,\alpha)$
Co^{58}	71d	0.15	0.47	$Ni^{58}(n,p)$


N
PARTIAL TOP VIEW
NORTH - EAST ELEVATION


Concrete shielding
Airlock
E x B plate
Substrate
"Heavy-met" collimator
Evaporator
Concrete shielding
Source chamber pump