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A MWPC POSITRON CAMERA

A MULTIWIRE PROPORTIONAL CHAMBER POSITRON CAMERA FOR STUDIES OF THE INTRACEREBRAL DOPAMINE METABOLISM

By

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part A

A Report

(On-Campus Project)

Submitted to the School of Graduate Studies

in Partial Fulfilment of the Requirements

for the Degree

Master of Engineering

McMaster University

August 1978

MASTER OF ENGINEERING (Engineering Physics) — McMASTER UNIVERSITY, Hamilton, Ontario

TITLE: A Multiwire Proportional Chamber Positron Camera for Studies of the Intracerebral Dopamine Metabolism

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NUMBER OF PAGES: vii, 49

ABSTRACT

The recent development of a technique for the synthesis of the molecule 5-(^{18}F) fluoro-dopa has opened a vast field of research into the study of the intracerebral metabolism. In order to take full advantage of this new tracer compound it will be necessary to use an imaging system which will be capable of providing three dimensional information concerning the rapid changes in activity as the ^{18}F travels through the brain. This report describes the results os investigations into a possible design for a device which would be capable of this type of dynamic imaging. The design in question employs multiwire proportional chambers (MWPC) as detectors of the .511 MeV gamma rays which result from the annihilation of the positron emitted in the decay of ^{18}F.

For comparison purposes, a breif review of various other types of positron tomographic systems which are presently in use or under development is presented. This review emphasises the resolution, data aquisition speed, and instalation cost for each of these designs.

In order to eliminate the need for costly research into the various design aspects of multiwire proportional chambers for use with positron annihilation radiation,

the design presented here relies exclusively on methods and designs developed and proven feasible by other groups. These are incorporated into a system to suit the present needs.

The design presented uses two pairs of 50x50 cm^2 MWPC's at 180° to each other and separated by approximately 50 cm. The chambers utilize electromagnetic delay-line readout techniques for the anode and wound bi-filar cathode planes. They are filled with a "magic gas" mixture at a slightly positive pressure. The effeciency of the chambers for .511 MeV photons is increased by employing "sandwich" type converters. Signals from the detectors are transfered to a small computor where they are stored for later tomographic reconstruction off-line.

On the basis of the working designs from which the present design has been drawn, one would expect the positron camera to have a sensitivity of better than 1000 counts/second-microcurie. The total costs of development and construction leading up to a working device suitable for clinical use, not including the cost of a dedicated computor, are estimated to be less than seventy five thousand dollars.

ACKNOWLEDGEMENTS

I wish to acknowledge the supervision of Drs. T.J. Kennett and E.S. Garnett throughout this project. I would like to thank Dr. C.E. Weber for his continuing assistance and interest, especially in the early phases of the design.

I would also like to thank W.D. Ramsay of the Cyclotron Laboratory, University of Manitoba for information and advice regarding the design and construction of multiwire proportional chambers.

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1. INTRODUCTION

A number of neurological and mental disorders are thought to be due to a disordered metabolism of dopamine in the brain. Among these are Parkinson's disease and schezophrenia.

Until recently, the problem facing researchers into these disorders was the lack of a method for the direct and atraumatic study of the intracerebral dopamine metabolism in man. The development of a technique for the synthesis of the molecule 5-(^{18}F) fluoro-dopa (Firnau et al. 1975) has led to a change in this situation. This positron emitting tracer compound has already been used to monitor intracerebral dopamine in baboons and promises to be a powerful tool in the study of the human brain (Firnau et al. 1976, Garnett et al. 1977).

There are two main points on which the optomism held for this new compound are based. The first is the nature of the 5-(^{18}F) fluoro-dopa molecule itself. Unlike fluoro-dopamine, which cannot enter the brain, fluoro-dopa is able to do so. Fluoro-dopa is the immediate precursor of fluoro-dopamine and once in the brain it is metabolised as if it were native dopa. Thus the intracerebral dopamine metabolism may be studied by observing the changes in the

^{18}F activity throughout the brain.

The second point is the use of the radio-isotope ^{18}F in labelling the dopa molecule. ^{18}F is a positron emitting isotope which makes it ideally suited for tomographic studies. Tracing back the paths of the .511 MeV gamma rays which are emitted at 180 degrees to each other upon annihilation of the positron is one of the best methods available for three dimensional image reconstruction. Other advantages of ^{18}F are its short half-life, and its low positron energy, which results in a short path length before annihilation thus improving image resolution.

Unfortunately the availability of fluoro-dopa does not in itself make it possible to observe the intracerebral dopamine metabolism. Also required is a system which will be able to detect the annihilation radiation from the decaying ^{18}F and use information obtained in this way to reconstruct the pattern of activity in the brain. Whats more, the system must be able to do so quickly enough to be able to detect the rapid changes in the activity pattern which are taking place due to the high flow rates present, while still being able to provide sufficient resolution to allow for the study of specific areas of the brain. More specifically, the system must be able to provide a spatial resolution of at least 1 cm while retaining the ability to construct time-activity curves at five second intervals for a period of the order of five minutes during which the study is conducted (Garnett 1977).

Herein lies the most serious problem presently facing this research. It would appear that most of the presently available tomographic devices for use in positron studies are not capable of satisfying these rigid requirements. Those which are either available or presently being developed which may eventually satisfy the necessary criteria would all appear to have a purchase price which would make them unavailable to all but the largest and richest research establishments.

The aim of the study presented in this report was to develop a design for a tomographic imaging device which would be able to satisfy the rigid requirements of speed and resolution at a price which would make it accesable to smaller research establishments on limited budgets, in particular the Department of Nuclear Medicine at the McMaster University Medical Center.

The remainder of this report is in three sections. The first, Chapter 2, is a breif review of a number of tomographic imaging devices available or under development. In each case the device was studied to see if it could satisfy the requirements of the intracerebral dopamine metabolism studies at an affordable price.

Next presented is a proposed design for a device based on the use of multiwire proportional chamber detectors which may prove suitable for use in these studies. This section of the report consists of a detailed list of design criteria, descriptions of the detectors, converters, electronics, and assosiated software, and a breakdown of the costs involved in development and construction.

Finally in Chapter 4, a number of conclusions are drawn and some suggestions are made with regard to the possible application of the design in the Department of Nuclear Medicine at the McMaster University Medical Center.

2. CURRENT STATUS OF POSITRON CAMERAS

Prior to presenting the proposed design for a positron imaging device, it is useful to breifly review the designs of other positron cameras which are either presently in use or being developed. These are reviewed under the criteria of intracerebral dopamine metabolism studies at McMaster University Medical Center; that is, sensitivity of at least 10^3 cps/microcurie, resolution of at least 1 cm FWHM, and low instillation costs.

The review is divided into four sections, each covering one of the various types of positron cameras to be found at present: the Anger type, the multicrystal type, the ring type, and the presently available MWPC devices. Although there has been some work investigating the use of solid state detectors in a positron camera (Yamamoto et al. 1975), this work has not progressed to the point where it justifies being included in the present review.

2.1 Anger Type Cameras

The basic design upon which the first positron cameras were based is that due to Anger (1963). This design involves the use of two large crystals of sodium iodide (NaI(Tl)) as detectors. The crystals are typically

1.2 cm thick and between 25 and 40 cm in diameter. They are set up facing each other and separated by about 30 to 60 cm. Mounted on each crystal is an array of photomultiplier tubes. The position at which the .511 MeV gamma ray interacted with the crystal is determined by observing the relative strengths of the signals from the various tubes which detect the event. Running the two crystal systems in coincedence enables the detection of the .511 MeV annihillation pair which in turn allows for tomographic reconstruction of the activity distribution of the positron emitter.

Various refinements have been made to the original design in order to improve resolution and sensitivity (see for example Budinger et al. 1976). The device of this type which appears to have the best characteristics with regards to sensitivity and resolution would appear to be that presently being marketed by the Searle Corp. (Muehlehn 1975). In this device graded absorbers are used to eliminate background from radiation which has been Compton scattered before reaching the detectors. Thus any gamma ray now reaching the crystal will be an unscattered .511 MeV photon and one can use both the Compton and photelectric interactions in the crystal for detection. This results in an increase of sensitivity of about a factor of five over conventional devices of this type. Devices with these absorbers are capable of a resolution of 1 cm FWHM with sensitivities of the order of 1.2 x 10^4 counts/ minute-microcurie (Harper et al. 1976).

Although these two figures are approaching the criteria for use in the proposed studies, the cost of the Searle device is of the order of $500,000.00, making it unsuitable for use at McMaster.

2.2 Multi-crystal Detectors

One of the more popular variations on the basic Anger design is that developed at the Massachusettes General Hospital (Brownell et al. 1977, Brownell and Burnham 1974). In this design the single large crystals with their arrays of photomultiplier tubes of the Anger camera are replaced with arrays of small crystals each coupled directly to its own photomultiplier tube. This reduces the cost involved in large NaI(Tl) crystals and in the complicated electronics for position determination in the Anger camera. This system will still be able to produce the same level of accuracy in reconstruction, i.e. 1 cm FWHM (Correia et al. 1976).

Because it is not practical to use the graded absorber technique on the individual crystals, however, detection of .511 MeV photons is limited to photoelectric interactions and the count rate with respect to the Searle device is reduced accordingly. Thus the sensitivity of of the M.G.H. camera is limited to something of the order of 10^3 counts/minute-microcurie (Hoop et al. 1976), which is below that required for the present studies. The efficiency of a device of this type might be improved by increasing the number of detectors and thereby increasing the detection solid angle, but due to the limited detection efficiency of NaI(Tl) crystals for .511 MeV photons it is likely that the costs of the device would become prohibitive long before the required sensitivity level would be reached.

2.3 Ring Type Devices

The third type of positron camera to be included in this review is the type which has detectors set in a ring about the source of the activity (Derinzo 1977). The best known of the devices of this type are the series of positron emission transaxial tomograph or PETT cameras (Hoffman et al. 1976, Eichling et al. 1977). The third generation of these devices, PETT III, has now been developed. It consists of six banks of eight NaI(Tl) crystal detectors in a hexagonal array with a 55 cm radius. Coincedence systems are set up between each detecto in one bank with all detectors in the opposing bank.

In recording data the array is rotated through sixty degrees in three degree steps. Operating in this way the system has a resolution of 1.35 cm FWHM with a sensitivity of 3×10^3 counts/minute-microcurie.

Thus one can see that besides lacking the sensitivity required for use at McMaster, the elaborate electronics system required for its operation makes the cost of a device such as PETT III prohibitive.

Other work in the development of ring type positron cameras is under way at the Montreal Neurological Institute. After initial work using devices employing solid state Si(Li) detectors and CdTe crystals (Yamamoto et al. 1975), studies are presently underway investigating the use of bismuth-germinate detectors (Yamamoto 1977). Judging from the properties of bismuth-germinate with respect to sodium iodide (Cho and Farukhi 1977) and from initial reports on this work, it would appear that this design may eventially reach the required level of resolution and sensitivity. The fact that development costs have already surpassed the one million dollar mark, however, makes this device an unlikely candidate for use at McMaster University.

2.4 MWPC Positron Cameras

The final type of positron camera to be presented in this review is that employing multiwire proportional chambers (MWPC) as detectors rather than scintillators or solid state counters (Perez-Mendez et al. 1976). The overall design of this camera is similar to the Anger type but now the large NaI(Tl) crystal with its coupled array of photomultipliers is replaced by a MWPC whcih provides the necessary positional information.

The positron devices which have been built using MWPC's have shown resolution of the order of 7mm FWHM for a system developed at costs which were an order of magnitude less than those encountered in other positron camera designs (Hattner et al. 1976, Reynolds et al. 1975). Their main weakness to this point has been a lack of sensitivity, the best reported to date being 675 counts/minute-microcurie. The reasons for this would appear to lie in problems involved with converters and readout schemes, points which will be discussed in detail in the next chapter.

It would appear the if these problems can be overcome, a positron camera design based upon MWPC detectors would hold the greatest promise for fullfilling the criteria necessary for use in intracerebral dopamine metabolism studies at McMaster University. Therefore, the proposed design for a positron camera presented in the remainder of this report is based on using MWPC detectors.

3. PROPOSED DESIGN FOR A MWPC POSITRON CAMERA

3.1 Design Criteria

As was indicated in the introduction presented in Chapter 1, the factors having the primary influence on the overall design of an imaging device for intracerebral metabolism studies are the need for a resolution of at least 1 cm and the ability to construct time-activity curves for this volume over a five second interval. In order to be able to fully realize this goal in a working device, the present design is worked out for conditions of the order of ten times more stringent than one would expect to find with the device in use in a clinical situation. An example of how this is done is using 1000 cm^3 for the volume of interest in which the device must be able to produce the desired imaging. In clinical practice one would expect to be interested in a much smaller volume of material. It is felt that the extra cost introduced by such over-designing is justified as a safety margin to ensure that a final working device would in fact preform as required. Furthermore if the device did operate to design specifications, this would result in a considerable reduction in the amount of the tracer which would be introduced into the brain, a factor which would be more than justified in terms of dose to patient.

If one wishes to keep the statistical counting error involved in the construction of the time-activity curves for each cubic cm volume below an acceptable level it is necessary to have a minimum detection rate of 10^3 counts/sec-cm^3 in the volume of interest. Assuming a volume of interest of 1000 cm^3, this means a detection rate for the system of 10^6 counts/sec., or correspondingly, a system deadtime of the order of 1 microsecond. This, it must be remembered, is for a system operating in a coincedence mode, resulting in the individual halves of the system requiring deadtimes of the order of 500 nanoseconds.

Another important design criteria is that of patient safety, resulting in the total amount of activity which may be introduced having a strict upper limit. Thus the detection criteria of 10^6 counts/second must be achieved without pushing the total activity available beyond a certain point. This total activity limit is of the order of 1 millicurie or 3.7×10^7 disintigrations per second. Thus the system must be able to detect at least three percent of all of the activity present in the brain if it is to be useful in dynamic studies of intracerebral metabolism. While this may seem to be a fairly easy task at first glance, one must remember that any practical system is limited by such factors as detector solid angle and efficiency. Thus one must attempt to use detectors with large solid angle and high overall efficiency while still keeping the system costs at an acceptable level.

Figure 1 indicates the basic features of the design presented in detail in the remainder of this chapter. It is aimed at satisfying the previously stated criteria as much as possible. The design employs two pairs of multiwire proportional chambers as detectors to provide maximum solid angle coverage at a minimum cost. Elaborate converters are used to convert the incident 0.511 MeV gamma radiation into low energy electrons which will easily be detected by the MWPC's, thus increasing the overall efficiency. Sectioned delay line readout coupled to fast electronics is used to reduce system deadtime. Finally tomographic reconstruction is accomplished off-line thus reducing system deadtime and cost.

Specific details of each of these features are now presented.

3.2 Multiwire Proportional Chambers (MWPC)

The development of multiwire proportional chambers has progressed to the point where they are a standard type of detector in nuclear and particle physics. The principals upon which their operation is based are now well understood and have been the subject of a number of reviews (Charpack 1970, Palladino and Sodonlet 1974). The popularity of MWPC's as detectors in experimental physics is due to a

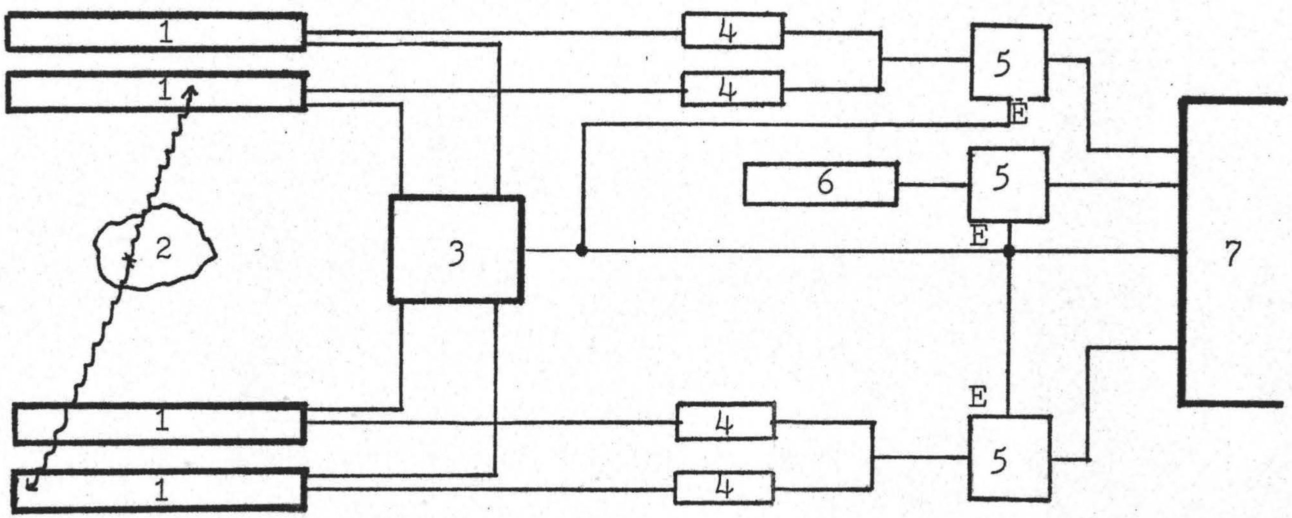

Figure 1. Basic Details of Positron Camera
1 MWPC, 2 source, 3 control circuits, 4 x-y processing circuits, 5 gates, 6 clock, E enable signal, 7 data storage (computor).

number of properties which make them extremely attractive. Among these are the ability to construct large, efficient chambers capable of providing high resolution and low deadtime. This is combined with costs which are far below those for solid state or crystal detectors.

Although all MWPC's operate on the same principal there are a number of different designs to be found. Each variation is aimed at exploiting a particular feature such as speed, position resolution, cost, etc. with the aim of obtaining the detector best suited for the task in question. While there are a large number of variations available, only a few designs are suited to use in a positron camera.

One such design is used in the positron camera described by Perez-Mendez et al. (1976). In this type of chamber position information is obtained from the cathode wires which are set at 90 degrees to each other in parallel planes with an anode plane between them. The anode is at high positive voltage with respect to the cathodes and is used for timing purposes (Kaplan et al. 1973). This type of chamber is capable of providing high position resolution but suffers from long chamber deadtime. Thus an imaging device employing this type of MWPC will provide excellent resolution for static studies but will be of little use in the dynamic situation (see Chapter 2).

A chamber design which would appear better suited to dynamic studies is one using both anode and cathode planes for position readout. It consists of an anode plane of wires at high positive voltage around which a cathode is wound as a flattened helix (Randell 1976, Lee et al. 1974). The winding of the cathode may be monofilar (Lee et al. 1973) or bifilar with every second turn grounded (Lee et al. 1972). Although the monofilar winding provides a factor of two better position resolution, the bifilar type is better suited for cases in which a high count rate capability is required.

The MWPC to be incorporated into the present design for a positron camera is therefore bifilar cathode type. The chamber design is illustrated in Figure 2. Details of the construction of a chamber are given by Randell (1976).

The procedure involves stringing thin wire on an insulating frame to produce the anode plane. The wire is connected to contacts on either side of the frame. Great care must be taken to ensure that the wires are evenly spaced so as to provide a uniform eletric field (Charpak 1970).

This completed, a second frame of the same thickness is mounted over the first in order to separate the two halfs of the cathode helix equally from the anode plane. A cathode is then wound at right angles to the anode wires with a pitch approximately equal to the anode wire spacing. A copper strip running the length of the frame grounds this winding. The strip is then covered with insulating tape and a second cathode wound between the first using the same

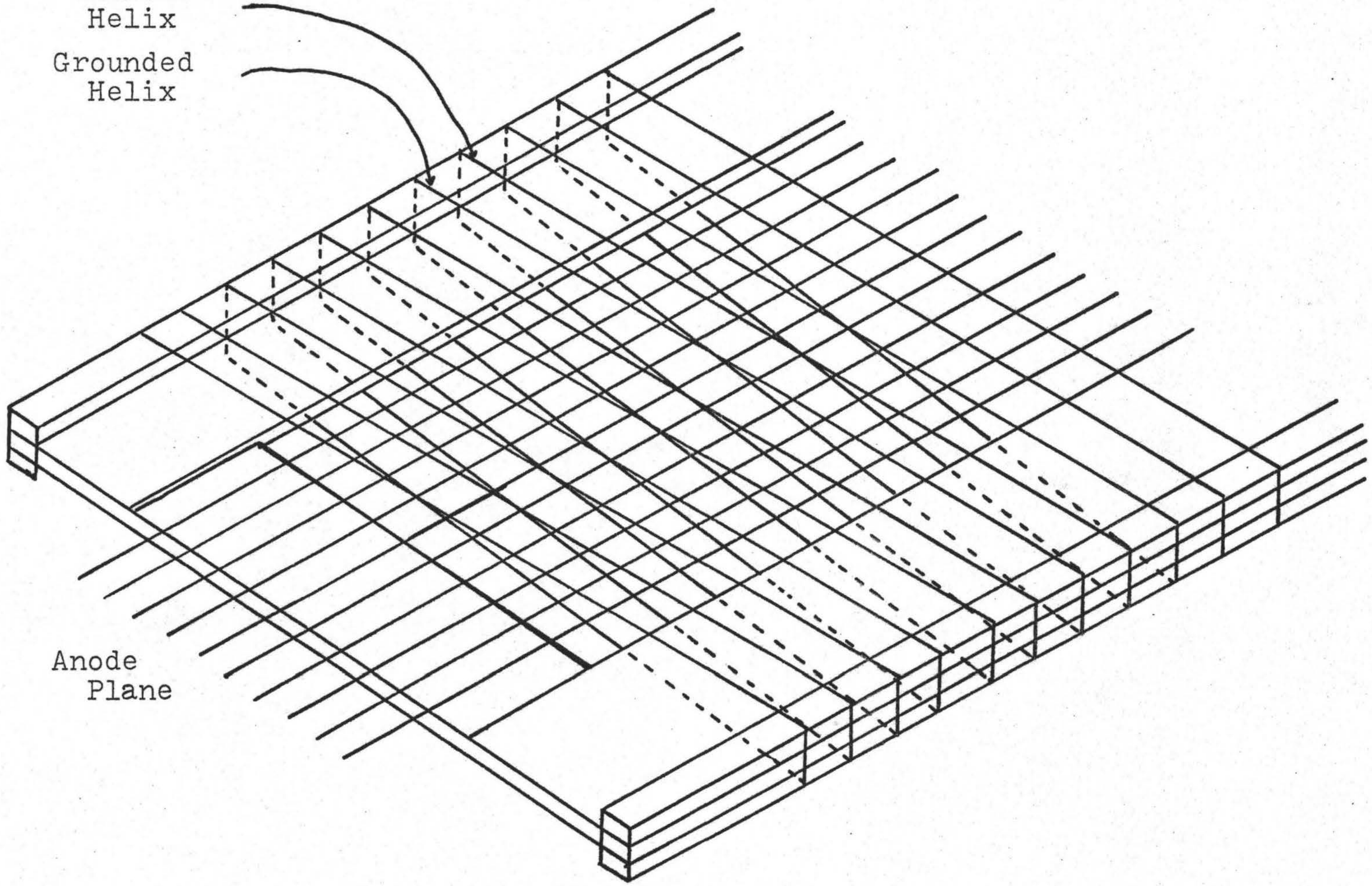

Figure 2. Bifilar Helical Cathode MWPC Windings (from Randell 1976).

pitch (Lee 1972). This results in the cathode behaving as a simple parallel transmission line thus eliminating any problems of frequency dependence or reflections from points of termination.

Once the chamber is completely wound it is placed in a protective frame of insulating material. For the insulating frames one requires a material with good mechanical strength combined with high resistance to surface breakdown in high electric fields. Randell (1976) recommends G10 fibre glass reinforced epoxy board for this purpose.

The frame thickness determines the anode-cathode wire plane spacing which in turn effects the chamber deadtime through the drift of the positive ions to the cathode plane. In most cases this effect, however, will be minor. The plane spacing is of greater importance with regards to possible sparking between planes. With this in mind, an anode-cathode plane spacing of at least 4 mm would be recommended.

The anode wires are normally 25 - 40 micrometer diameter gold plated tungsten or copper. The diameter depends upon the wire spacing. Since by using delay line readout techniques (refer Section 3.3) it is possible to achieve resolution of better thanone half the wire spacing in either plane (Charpak 1970), only relatively wide spacing is required in obtaining the 1 cm resolution hoped for in reconstruction of the images. An upper limit is placed on the wire spacing, however, by the requirement of about 2.5×10^5 V/cm electric field around the wires for suitable electron amplification (Charpak 1970). Thus to obtain suitable fields while keeping supply voltages within reasonable limits, an anode wire spacing of no greater than 5 mm is recommended. Thiswill result in approximately 2 mm x-y position resolution for each MWPC used in the camera.

For the cathode wire, copper plated tungsten wire with diameter of the order of 50 to 100 micrometer is recommended (Randell 1976). Both anode and cathode wires must be strung under tension to ensure that they do not sag as a result of a change in temperature. The amount of tension required is determined by the coefficient of thermal expansion of the particular type of wire employed in each case.

As illustrated in Figure 1, a pair of MWPC's complete with gamma converters (Refer Section 3.4) is placed in a leak-proof box to form one half of the detection system. The box enables the MWPC to be in an atmosphere of the gas needed for their operation. A number of groups have investigated the properties of various gas mixtures with regards to breakdown, pulse height, shape, and rise time, and pressure. (See Lacy and Lindsey 1974 and references therein). These studies would indicate that the best gas mixture to be used with the present chamber design would be that referred to as "magic gas" (Charpak et al. 1971). It consists of 70% argon, 29.5% isobutane, and 0.5% Freon

13B1. The chamber environment is maintained slightly above atmospheric by flowing the magic gas through it.

As was stated previously, one of the major factors resulting in the selection of MWPC detectors for the present design is the ability to construct large detectors which would thus present large solid angles, thus increasing the overall system efficiency. For the present system, detectors with active aresa of a minimum of 50 x 50 cm^2 are recommended.

Briefly reviewing the design presented in this section: each of the four detectors used in the positron imaging device are MWPC's with 50 x 50 cm^2 active areas.*
They are the bifilar helix cathode type with the cathode wound in a flattened helix at 90 degrees to the wires in the anode plane. The wires in the anode plane are spaced on 5 mm centres and held at high positive voltage. The cathode is wound at a 5 mm pitch and separated from the anode plane by a 4 mm gap. It is held near ground potential. Magic gas is recommended for use with the detectors.

3.3 Electronics

The success of a design for a positron camera employing ,WPC's as detectors is dependent upon the development of an electronic systems which will be able to accurately process and transfer the detector information

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*A pair of detectors is used on either side since this is found to greatly reduce background problems (Hattner 1976).

at speeds high enough to enable dynamic studies to be carried out. This is no simple task since MWPC's have been constructed with count rate capabilities of over 10^6 counts per second per wire (Shapiro et al 1976).

There are three main sections of the electronics proposed for use in the present design. The first two are the systems for obtaining and digitizing the position information from the anode and cathode planes respectively. The third is the control system for determining what information is to be passed on to the computor for storage and later tomographic reconstruction.

A large number of anode wire readout schemes for MWPC's have been developed over the past decade. These range from systems employing individual wire readout requiring an amplifier and associated electronics for each wire (Aebischer et al. 1972) to delay line techniques requiring only a pair of amplifiers per plane (Grove et al. 1972, 1973, Lee et al. 1974). Individual wire systems offer high speed and excellent resolution but are complicated and costly. Delay line techniques are cheap, simple and still result in high resolution. Their disadvantages be in long dead times and high signal attenuation for use with large chambers.

The anode readout system proposed for use in the present design is a modified version of a delay line technique developed by Bryman, Cresswell, and Skegg (1976). The modifications made to the system are the use of four delay lines, each one handling one quarter of the anode palme rather than a single line for the entire plane, and the introduction of integrated circuits to replace discreet components in the electronics. These changes were made to reduce chamber dead-time and simplify the assembly of the electronics.

Figure 3 shows a block layout of the anode readout system. Signals from the anode wires pass into a common base transistor buffer system operating in a linear mode which reduces the pulse dispersion resulting from the direct connection of chamber wires to the nodes of the delay line. The delay line is made up of high speed, 50 ohm impedence coaxial cable (RG174) in 4 ns sections connected between the outputs of the buffer transistors. To equalize the signal rise times from the various wires a pair of dispersion networks of lumped inductance and capacitance is employed, one on each end of the delay line. The output of each of the dispersion networks is fed into an amplifier and then a constant fraction discriminator to ensure that only signals from true events are recorded. The amplifier and discriminator used may both be contained in a single integrated circuit such as the LD604*, details of which are given in the Appendix.

The output of one discriminator is then used to start a time-to-digital converter (TDC) while the stop signal from the other is first passed through a delay

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*LeCroy Research Systems Corp., New York.

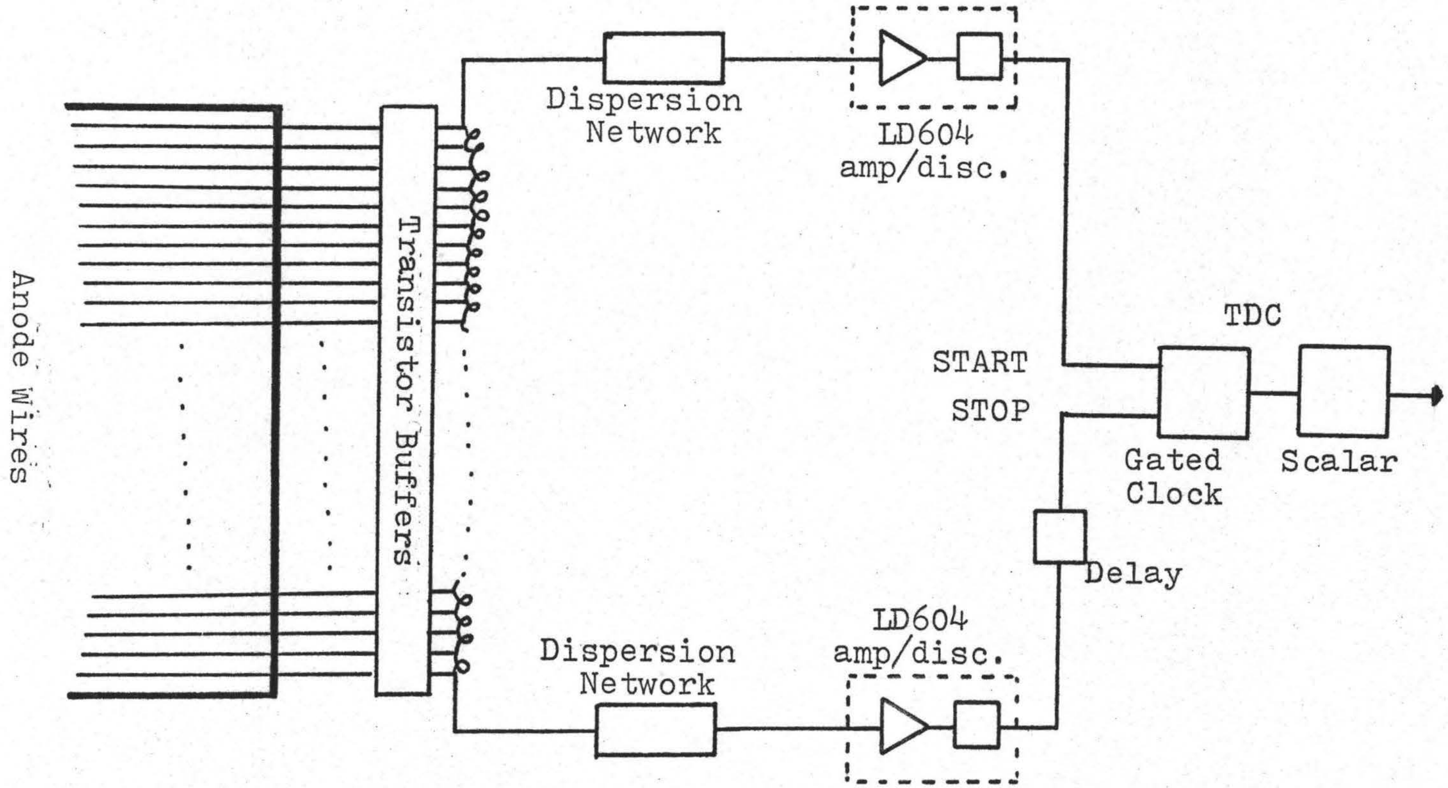

Figure 3. Anode Readout System

equal to the total delay of the delay line. This ensures that the stop signal always arrives last. The position of the wire which sensed the event is determined by the time between the start and stop pulses. This time is digitized by the TDC and then made available for transfer to the computor.

There are four such networks on each anode plane. Each records events for 25 wires of one quarter of the anode plane. The deadtime for each is the sum of the anode-wire-delayline combination (approx. 150 ns), an equal delay on the stop line, plus the delay in the remaining electronics (approx. 20 ns), resulting in a total network delay of the order of 325 nanoseconds. Each of the networks on a given anode plane is set up in anti-coincidence with the other three to ensure that no ambiguous information is processed because of two sections attempting to output at once. The prompt anode pulse on the delay line is tapped to set the flag used in the anti-coincidence circuits.

Although the cathode readout will also employ electromagnetic delay line readout, the system used to accomplish this is quite different from that employed on the anode. The main reason for this is that the bifilar helix cathode itself acts as a delay line and thus does not require an external delay. Other factors such as the high attenuation on the line also come into play.

The proposed design for the cathode readout system is that due to Lee et al. (1972). The only changes to the original design proposed for use in this design are in tap positions and the introduction of integrated circuits to replace discreet components. A block diagram of the proposed cathode readout system is given in Figure 4. An aim of the design is to provide deadtimes of the same order as those for the anode readout system.

The taps for the recording of the cathode signal are located on every eleventh turn of the ungrounded helix or approximately every 5 cm of chamber length. This corresponds to a tap to tap delay on the cathode wire of approximately 120 ns and a corresponding attenuation factor of approximately 0.2 (Lee et al. Figure 2, p181). The taps are divided into three types which repeat cyclically for three cycles along the helix. The outputs of the LD604 amplifier-discriminators for all taps of a given type are ORed together. The output of the OR is used to stop the TDC for that group. The start pulse for the TDC's of all three groups is a fast pulse derived from the anode wires of the chamber. A set of gates and flip-flops is used to record the first tap in each set which sensed the event. The fast anode pulse is also used to reset the system if no output is requested by the control logic within the system deadtime. If an output is requested, the output of the shift register and the three TDC's are passed to the computor. The shift register provides information regarding

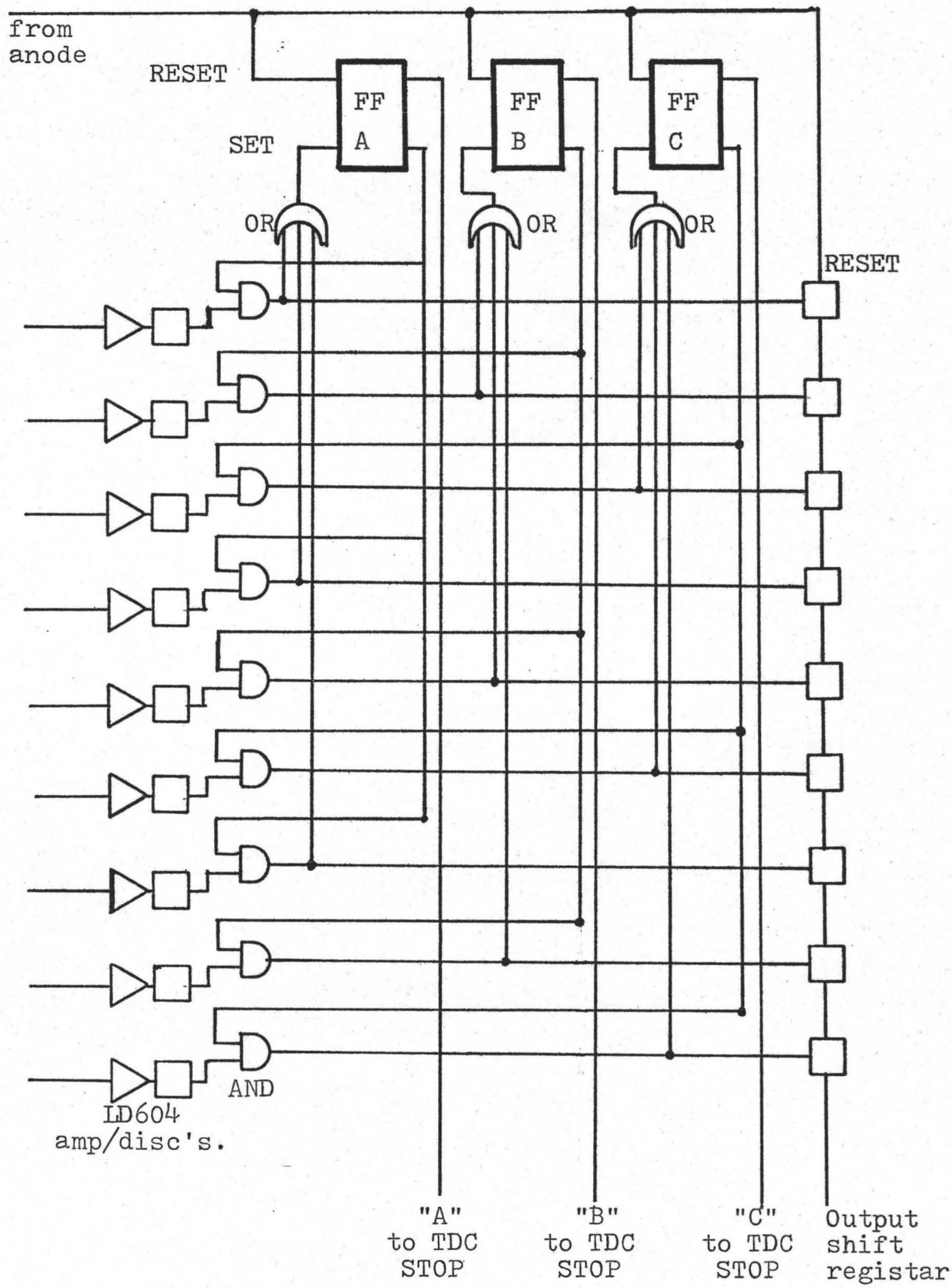

Figure 4. Cathode Readout System

which taps recorded the event. Position information is obtained by taking the difference in the times between the two largest of the three observed TDC outputs. This method helps eliminate problems caused by events occuring too close to a tap and by variation in the delay of the START pulse from the anode. This is accomplised by the software off-line in order to reduce hardware deadtime for the camera.

The final part of the electronics for the proposed positron camera design is the control circuit. This circuit determines if an event is valid and should be passed on to the computor for storage. The information to be passed is the x-y position information from the detectors in each half of the camera and, since the device must be able to construct time-activity curves, a digital time signal indicating when the event took place.

The criteria under which the control system operates is that the camera has actually detected the gamma rays from an annihillated positron. This criteria requires that the two halfs of the camera detect the gamma rays in coincidence. Furthermore, since each .511 MeV gamma ray can trigger only one MWPC of the pair making up each side (due to the converter characteristics, see Section 3.4), the MWPC's making up a side must respond in anti-coincidence.

A block diagram of the control system is shown in Figure 5. Not shown is the anti-cioncidence circuit on each MWPC to ensure that only one part of the anode presents a

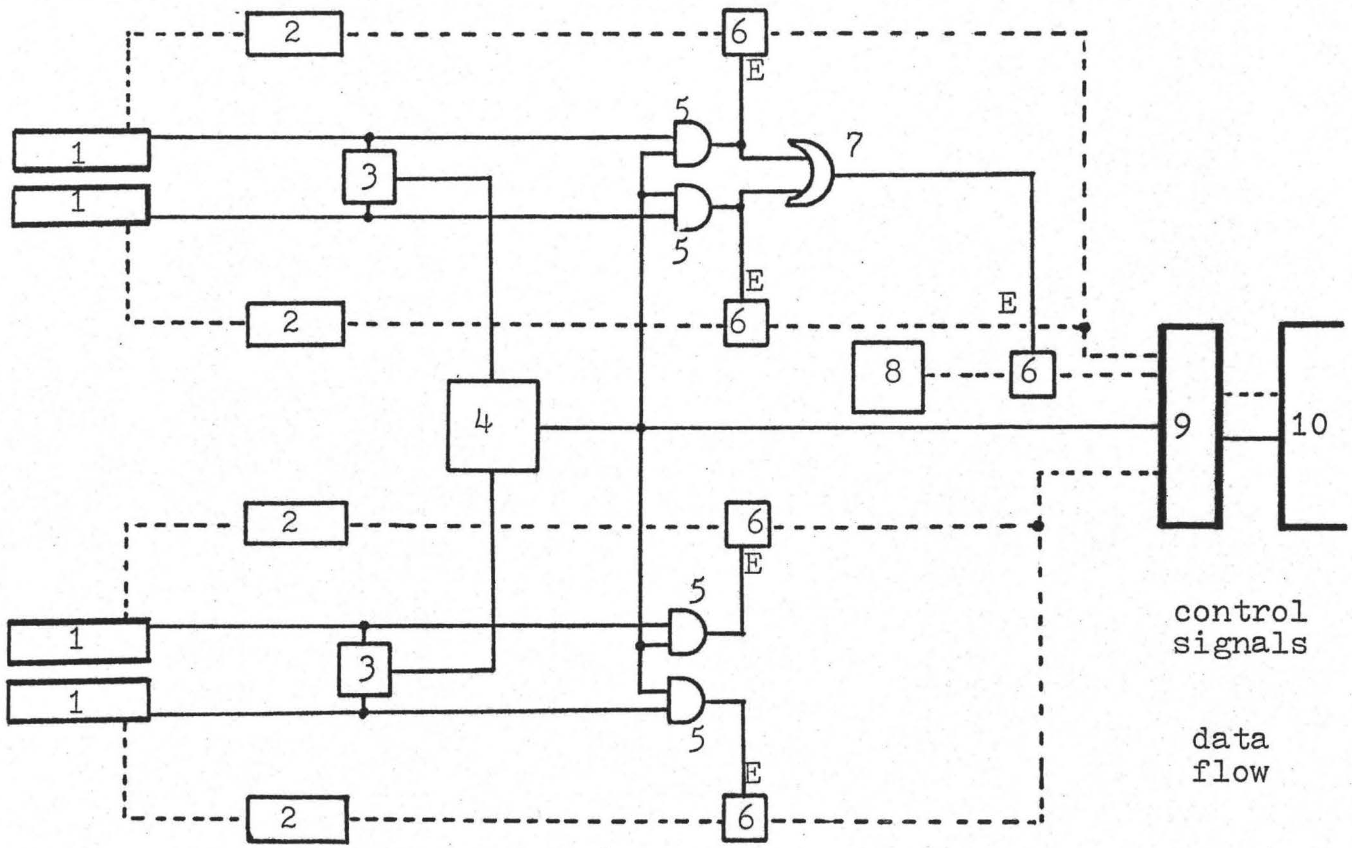

Figure 5. Control Electronics
1 MWPC, 2 x-y processing circuits, 3 anti-coincidence, 4 coincidence, 5 AND gate, 6 gate, 7 OR gate, 8 clock, 9 output buffer, 10 computor, E enable signal.

signal at a time. The electronics previously described for the anode and cathode readout are shown in this figure as boxes labelled x-y. Included in x-y is a flag to enable the software to know which MWPC of the pair produced the information. Also not shown in the figure are the various delays needed for timing purposes or the busy signals required to ensure that nothing is restarted before an event is processed.

The time window for the anti-coincidence circuit in each half is set to about 100 ns, which is approximately twice the maximum delay of any prompt anode pulse on the anode delay lines. The window for the master coincidence circuit is set at about 500 ns which covers the maximum chamber deadtimes in either half to the camera. Signals passed by the control system enter a buffer and are then passed on to a computor or other mass data storage device. For the data buffer and much of the control, a system such as CAMAC is recommended.

3.4 Converters

The main reason that MWPC's do not at present enjoy wide spread use as detectors in positron imaging devices is that the chamber gas has a very low conversion efficiency for .511 MeV gamma radiation. That is, the probability of a gamma ray interacting with the chamber gas to produce a charged particle which might be detected in the MWPC is very low at this energy. Thus in order to employ MWPC detectors in a positron camera, it is first necessary to fit them with some type of converter which will increase their detection efficiency for the radiation of interest.

With this in mind, a number of both theoretical and experimental studies have been undertaken in recent years with the aim of determining the optimum design of a converter for use with .511 MeV radiation (Chu et al. 1976, Jeavons and Cate 1976, and references therein). These studies have come up with a number of conditions which must be satisfied in order to acheive maximum conversion efficiency.

For .511 MeV radiation it is found that the converter material should have a high atomic number since the interaction probability increases with Z. One wants the surface-to-volume ratio for the converter design to be high so that the incident photons see as much material as possible. Also, once the interaction has taken place, the resulting photo-electron must be able to escape the converter and enter the MWPC in order to be detected.

It has been found that the above conditions may be satisfied by using a solid block of a material such as lead perforated with a large number of small closely spaced holes. With the proper choice of hole size, spacing, and pitch, there is a good probability that a gamma ray will interact with the lead and the resulting photo-electron will escape into the nearest hole. Then by applying an electric field it is possible to have the electron drift out of the converter and into the MWPC. Results of a detailed study of the determination of the optimum hole size, spacing, and pitch are given by Jeavons and Cate (1976).

In the same paper they present a converter design which would appear to be the most efficient developed to date. It is this type of converter which is recommended for use in the positron camera design given in this report.

The converters are so-called "sandwich" type. Each consists of 75 lead-bismuth* plates, each 0.25 mm thick, interleaved with 0.1 mm thick glass fibre epoxy resin sheets. The holes are 0.8 mm diameter on a 1 mm pitch. Holes are chemically etched in the lead-bismuth sheets and drilled in the epoxy.

A MWPC fitted with two such converters, one coupled on either side of the cathode helix, was determined to have an efficiency of better than 15% for 660 keV photons from ^{137}Cs. One would expect effeciencies of at least this high for .511 MeV annihillation radiation. Using two MWPC's fitted in this way on either side of a positron camera, one would expect a singles efficiency per side of better than 30% or an overall coincidence detection efficiency for the device of the order of 10%. This level of efficiency compares

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*CERROBASE, 44.5% Pb, 55.5% Bi, T_m= 124°C favorably with that presently available on devices employing sodium iodide crystals for detectors (Muehlehn 1975). Figure 6 illustrates a MWPC fitted with a pair of converters.

It would appear that the next major breakthrough in converter design will be in the use of channel-plate converters of high density lead glass (Woodhead and Eschard 1971). Because it is still in the developmental stages, however, this technology has not been recommended for use in the present design. Since it may be practical by the time construction of this type of positron camera might be undertaken, however, the reader is refered to Jeavons and Cate (1976) and Chu et al. (1976) for a summary of work to date.

3.5 Software

The development of the software needed for the operation of the proposed positron imaging device is a task of the same magnitude as the construction of the camera itself. Extensive routines will be needed for data aquisition and storage, coordinate reconstruction, and, most importantly, tomographic imaging of the data. Details of the various routines will require a great deal of study. These details are outside of the context of the present report. Discussion at this point will be limited to a

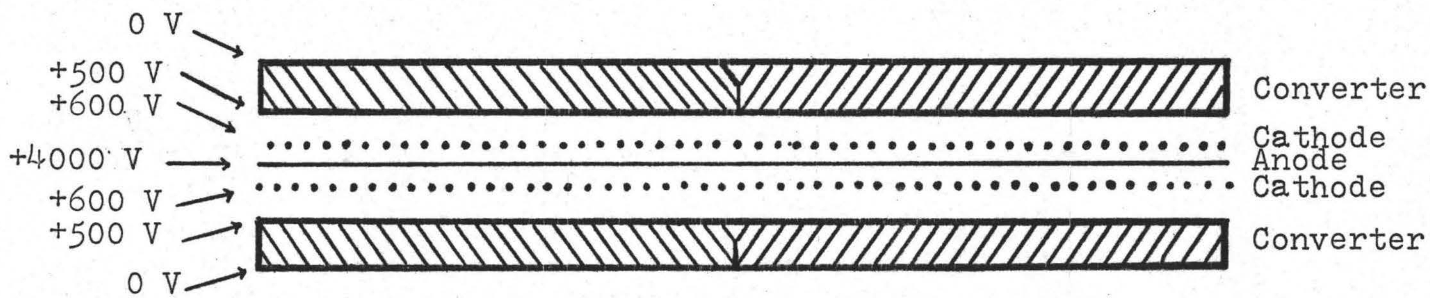

Figure 6. MWPC Fitted With Converter Plates
Not to scale, voltages shown are approximate values which may not apply exactly to the case of an operational chamber.

breif outline of the major tasks that would be handled by the software system.

The first major task will be recieving data from the hardware and storing it for later use. This must be done quickly enough so as not to increase the overall system deadtime. The input data will be in the form of digital representations of time intervals. There will be four such signals, one anode, three cathode, for each of the MWPC's involved in recording the event. Along with these will be coded signals indicating which MWPC's responded and the time at which the event was recorded. Thus the system must be able to input at least nine digital words within the dead-time of the system, or of the order of one word every 100 nanoseconds. According to present design, this is the only task to be preformed on-line.

The next software task will be the determination of the coordinates at which each of the .511 MeV photons was detected. This will involve finding the two largest of each group of cathode signals and using them to determine one coordinate for each detector. Then the anode pulse times will be used to find the second coordinate for each. The x and y coordinates for each detection point will then be stored, along with their detection time, for use in the final data analysis.

The largest and most complicated part of the soft-ware will be needed for constructing the tomographic images from the coordinate data. The results of a number of studies of various methods of reconstruction have been published. A number of these deal specifically with the case of data obtained using MWPC detectors (Townsend et al. 1978, Chu and Kwok-Cheong 1977, Lim et al. 1976, Cho et al. 1976, Chang et al. 1976). It is probable that one of these algorithms might be used in the development of the necessary software for use with the device discussed in this report. Even if that is the case, however, it is likely that it would require a minimum of a year to develop a working software system.

3.6 Camera Construction

Before presenting a cost breakdown for the positron camera proposed in this report it is useful to first breifly discuss a number of points which might arise in the event a decision was made to proceed with construction of such a device at McMaster University. The particular points to be discussed are the wiring of the chambers and the construction of the converter plates.

As was stated in Section 3.2, one of the crucial points in the construction of a MWPC is uniform wire spacing. Randell (1976) found that this was one of the most important factors in determining whether or not the completed MWPC would operate according to design. He found that it was highly unlikely that a large MWPC could be wired by hand and still operate reasonably well.

It would therefore be recommended that the MWPC's be wound using a wire-chamber winding machine.(See for example Bird et al. 1971). This is a fairly straightforward device which could be assembled for less than three hundred dollars and which would allow for high precision chambers to be assembled with relative ease.

The next point to be discussed with regard to chamber construction is the assembly of the converters mounted on the MWPC to increase their efficiency in the detection of .511 MeV gamma radiation. As one may deduce from the description given by Jeavons and Cate (1976), these are very complicated devices which require special techniques and equipment for their construction. It is not likely that facilities such as those required for precision chemical etching of the Pb-Bi foils would be available at centers where active research into MWPC positron devices is not taking place. Also, it would not be economically feasable to set up the necessary facilities if one only wished to produce the eight converters required for a single positron camera.

Thus it would seem more reasonable to purchase the complete converter assemblies from an institution already set up to produce these devices, One of the first sources to investigate would be the Department of Physics of Queens

University in Kingston Ontario where work is being done on MWPC's for use in high energy experimental physics (Douglas et al. 1976). On the basis of material costs and the complexity of the assembly process, one would estimate the price of converters to be of the order of $1500.00 each.

3.7 Cost Estimates

In this section an attempt is made to estimate the cost of producing a working positron camera according to the design presented in this report. In considering the figures presented here it must be kept in mind that they are rough estimates intended for use in consideration of the overall feasability of the design presented rather than a precise cost breakdown upon which the construction plans would be based. Also to be kept in mind is the fact that some cost, in particular labor and development costs, will be greatly affected by the approach which is taken. For example, the cost would be considerably reduced if much of the final design and development along with much of the construction was preformed as work towards a graduate degree in a field such as biomedical or electrical engineering, in comparison to what would be the case if a full time technician were hired for these tasks. The same applies to the development of the system software.

With this in mind, a cost estimate for a MWPC positron camera is presented. All price estimate are in Canadian dollars as of July 1978.

The costs of the positron camera proposed may be broken down into three main catagories: design and development, hardware, and labor. The design and development costs are in two main parts. The first is further investigations into the proposed design, the obtaining of price quotations, and the drawing up of the final blueprints. Estimates here are based on the assumption that the work will be done either by a present member of the departmant's staff or a graduate student. The second part is the development of a software system for use on an operational system. This estimate allows for a full time programmer working solely on this task. Also included are the computor costs which will result from the testing of the software package.

The hardware costs include all costs of material going into the MWPC's, electronics, system housing, and a wire winding machine. Cost here are for materials only, with the exception of the converters which are assumed to be purchased assembled (see Section 3.6).

The labor costs include all shop costs and the cost of assembling the device. The assumption is made that a full time technician is hired for construction of the camera.

A breakdown of the costs is given in Table I. A breakdown of the costs of each MWPC is given in Table II.

Table I

Estimated Cost of a MWPC Positron Camera

Development		
Further studies and design work		5000
Software development		20000
	Total	25000
Hardware		
4 MWPC's (see Table II)		16000
Camera housing assembly		2000
Control and logic electronics		500
Wire chamber winding machine		300
	Total	18800
Labor		
Shop costs		10000
Assembly		20000
	Total	30000

Grand total less than $75,000.00.

Table II

Estimated Hardware Cost Per MWPC

G10 board, wire, insulation, anode delay line	200
fast electronics for readout, including TDC's, amp-disc., transistor buffers, logic gates, etc.	700
circuit boards and contact boards for wire connections	100
2 sandwich type converters	3000
Total	$4000

As can be seen from Table I, one would expect the total costs leading up to a working positron imaging device to be of the order of $75,000.00.

It must be kept in mind that this figure does not include the cost of the computor which will be needed in the operation of the camera. A dedicated computor was not included in the cost estimates for the Department of Nuclear Medicine at the McMaster University Medical Center since it was assumed that use could be made of the existing computor facilities in the department. If it would become necessary to add a computor, this would increase the cost estimates by approximately fifty thousand dollars, the actual cost depending on whether it was used strictly for data collection or if it was also employed for off-line data analysis.

4. CONCLUSIONS

It would appear certain that multiwire proportional chambers will be playing an increasingly important role in the field of nuclear medicine. Use in nuclear and particle physics has shown this type of detector to have resolution and deadtime characteristics that are equal to or better than the detectors in use in present-day nuclear medicine imaging devices. This is combined with typical costs that are of the order of a factor of ten less than a comparable system employing crystal detectors. Their main weakness to this point has been a lack of efficiency for the detection of the radiations of clinical interest. Work on converters, however, would appear to have eliminated this problem to the point where a system employing MWPC detectors would be expected to have a sensitivity equal to or greater than most employing more conventional detectors.

On this basis, the author recommends that the Department of Nuclear Medicine at McMaster University Medical Centre initiate a program of further studies into the development of a positron imaging device for intracerebral dopamine studies which employs a multiwire proportional counter detector system. As a first stage it would be recommended that detailed studies be carried out into a more precise cost breakdown as well as further work on the proposed design presented in this report.

It is the belief of the author that a MWPC device would be the only type which would be able to satisfy the resolution and sensitivity requirements of dynamic brain studies at a cost which would be acceptable to a smaller institution. Furthermore, due to the relatively new technology involved in this design it is not likely that a device of this type would be commercially available in the forseeable future, thus necessitating the development by the group intending to make use of it.

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APPENDIX

The LD604 Integrated Circuit

The following two pages provide technical data on and the specification of the Type LD604 hybrid integrated circuit. This circuit has been chosen for use in the electronic scheme of the positron camera previously described. The cost of the LD604 was $16.00 (US) in 1976. The cost breakdown given in Section 3.7 assumes that this has not changed signifigantly.

TECHNICAL DATA

LRS

Hybrid Circuit / Type LD604

Multiwire Proportional Chamber Discriminator

FEATURES:

- **Low threshold of −200 μV** assures operation with all chambers and gas mixtures and triggers low enough on input risetimes to eliminate input signal shape as a source of time dispersion.
- **Differential inputs** help minimize noise and permit operation with twisted pair or other transmission lines.
- **Excellent threshold stability** of < 2 μV/°C assures reliable operation over typically varying experimental conditions.
- **Low time slewing** in conjunction with low threshold provides minimum time dispersion and optimum spatial resolution.
- **Differential outputs** may be used to drive twisted pair.
- **ECL output levels** suitable for driving transmission delay lines.
- **Compact packaging** in standard 16-pin dual in-line package permits discriminator to be mounted in sockets right on the chamber.

Preliminary: February, 1975

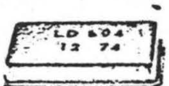
The LRS Model LD604 is a high-speed discriminator designed to optimize the usefulness of multiwire proportional chambers in high energy physics experiments. As opposed to conventional designs where long amplifier risetimes (30-40 ns) and high input thresholds (1-5 mV) combine to create excessive time dispersion (discriminator slewing), the LD604 has a low minimum threshold of −200 μV and an inherent amplifier risetime of 4 ns, which essentially eliminates the electronics as the source of time dispersion in the system. This fact permits narrower coincidence gates (which simplify track recognition by admitting fewer accidentals) and reduces chamber deadtime. The low threshold additionally permits the use of non-magic gas and lower chamber high voltage which help to increase the life of the chamber.

The high impedance inputs of the LD604 are differential in contrast to single-ended conventional designs, permitting the use of lower thresholds without danger of adverse effects from common mode noise upon the efficiency of the chamber. The LD604 may be mounted either on the chamber or at the end of a transmission line with a low value termination selected to minimize the effect of chamber capacitance and to match the impedance characteristics of the system (eg., 100 Ω for twisted pair).

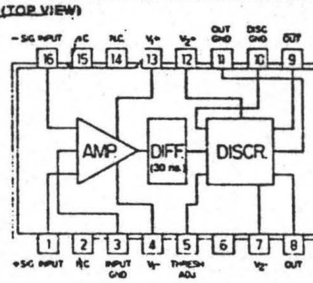
The LD604 outputs are standard ECL logic levels (both normal and complementary), suitable for driving transmission delay lines. Output duration is approximately equal to $30 \ln V/V_T + 15$ ns, where V is the input amplitude and V_T is the threshold setting.

The Model LD604 is packaged in a standard 16-pin dual in-line Kovar header which fits standard IC sockets.

PACKAGING



LOGIC DIAGRAM (TOP VIEW)



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SPECIFICATIONS

Hybrid Circuit/Type LD604

MULTIWIRE PROPORTIONAL CHAMBER DISCRIMINATOR

INPUTS

Pin Nos.	Description	Signal Characteristics	Function
1, 16	Signal Input	> threshold fires discriminator	Receives differential inputs
5	Threshold Adjust V_T	Negative; approximately V_T x 100μV/V	Controls threshold

OUTPUTS

Pin Nos.	Description	Signal Characteristics	Function
8	Normal Output	Quiescently −1.6 V, −0.8 V during output	Discriminator output
9	Complementary Output	Quiescently −0.8 V, −1.6 V during output	Discriminator output

Outputs require external pulldown resistors.

SUPPLY VOLTAGES

12, 13	+6 V, 35 mA
4, 7	−5.2 V, 70 mA

ELECTRICAL CHARACTERISTICS

Parameter	Specifications
Input Output Delay	14 ns
Double-Pulse Resolution	40 ns: two identical pulses 135 ns: first pulse 10X second (with τ_F = 40 ns)
Input DC Level	Ground.
Threshold Control Impedance	100 KΩ.
Output Width	Logarithmic time over threshold*
Threshold Temperature Coefficient	< 2 μV/°C.
Slewing	4 ns from 2X to 20X threshold: (see graph below.)
Power	Approximately 350 mW.

*15 ns minimum: 80 ns at 10X threshold. Approximate output width (ns) for square input pulse is 30 ln (V/V_T) +15, where V is input signal amplitude and V_T is threshold control voltage.