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A Large 2D PSD for Thermal Neutron Detection

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Abstract

A 2D PSD based on a MWPC has been constructed for a small angle neutron scattering instrument. The active area of the detector was $640 \times 640mm^2$. To meet the specifications for neutron detection efficiency and spatial resolution, and to minimise parallax, the gas mixture was 190kPa ^3He plus 100kPa CF_4 and the active volume had a thickness of 30mm. The design maximum neutron count-rate of the detector was 10^5 events per second. The (calculated) neutron detection efficiency was 60% for 2Å neutrons and the (measured) neutron energy resolution on the anode grid was typically 20% (fwhm).

The location of a neutron detection event within the active area was determined using the wire-by-wire method: the spatial resolution ($5 \times 5mm^2$) was thereby defined by the wire geometry. A 16 channel charge-sensitive preamplifier/amplifier/comparator module has been developed with a channel sensitivity of 0.1V/fC, noise linewidth of 0.4fC (fwhm) and channel-to-channel cross-talk of less than 5%. The Proportional Counter Operating System (PCOS III) (LeCroy Corp USA) was used for event encoding. The ECL signals produced by the 16 channel modules were latched in PCOS III by a trigger pulse from the anode and the fast encoders produce a position and width for each event. The information was transferred to a UNIX workstation for accumulation and online display.

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1. Introduction

A small angle neutron scattering (SANS) instrument with modest neutron flux was being constructed on the Australia research reactor HIFAR. The instrument had a 5m long neutron beam collimator before the sample and a sample to detector distance that could be varied in length from 1.5m to 5m. An efficient neutron detector was required. There had been a number of detector systems constructed for similar instruments[1-5] and relevant knowledge was included in this project. In general, the design parameters for the detector were defined by the intensity of the neutron source, the SANS instrument optics, and the limitations of structural materials for the detector chamber construction.

The overall dimensions of the active area were determined primarily by the types of SANS experiments to be conducted on the instrument through a parameter related to the angle subtended by the detector at the sample position. An active area of $640 \times 640 mm^2$ was adequate to collect data for the majority of experiments.

Neutrons were detected by capture in ^3He gas according to the following:

$$^3He + \text{neutron} \rightarrow {}^3H + {}^1H + 764keV \quad (1)$$

The detector efficiency was a design parameter of prime importance. From the cross-section for thermal neutron absorption, the number of ^3He atoms required to meet the design specification of >60% detection efficiency for 2Å neutrons, was calculated. It was then a matter of satisfying the no-parallax condition at the minimum sample-detector distance, and the restrictions on the total pressure due to the mechanical strength of chamber materials, to arrive at a balance between the active volume thickness and ^3He gas pressure. The values that satisfied these conditions were a thickness of 30mm and a ^3He partial gas pressure of 190kPa (absolute).

The pixelation or 'spatial resolution' of the active area was dependent on the instrument optics[6]. It was demonstrated that a spatial resolution of $5 \times 5mm^2$ was the minimum required with rebinning to $10 \times 10mm^2$ for some data. The relatively low spatial resolution of the detector meant that the wire-by-wire method for position readout could be used which required 128 readout channels for each of the two orthogonal cathode grids.

As indicated by Equation 1, a charge cloud would be generated by the 191keV triton and 573keV proton. The size of the cloud would be determined primarily by the partial pressure of a stopping gas since the stopping power of ^3He gas was too low at these pressures to limit the ranges of the particles to acceptable values. Extensive calculations were undertaken using the TRIM computer code[7] to determine the charge cloud distribution resulting from the primary capture event in a range of gas mixtures. With the partial pressure of the ^3He (190kPa) determined by the neutron detection efficiency, the task was to determine the type and the partial pressure of the stopping gas required to produce a charge cloud distribution consistent with the spatial resolution of the detector (5mm). CF_4 was selected as the stopping gas. Figure 1 is the calculated charge cloud distribution for the selected gas mixture of 190kPa ^3He plus 100kPa CF_4.

The GARFIELD computer code (CERN Library) was used for electric field calculations to specify details of the grid geometry and to investigate the sensitivity of detector performance on variations in chamber geometry. This study assisted with the specifications for the mechanical tolerances on the chamber (in general ±0.04mm) and the grid construction (in general ±0.02mm).

The detector was to operate in a vacuum vessel. This created an additional ~100kPa pressure differential across the chamber walls that had to be taken into account in calibrating the detector geometry at laboratory pressure. The location in the vacuum vessel also presented an additional consideration in the design of the readout electronics front end in terms of the heat load. As a result, the front-end electronics were mounted in an enclosure at laboratory pressure.

2. The Chamber

The pressure chamber was constructed from aluminium alloy 6061-T6. Aluminium had a unique combination of good mechanical strength and good neutron transmission properties. The 90mm thick backplate provided structural rigidity under the maximum 350kPa gas pressure load. There must be minimum mechanical deflection under load to ensure the tensions in the grid wires were maintained under working conditions.

To minimise the thickness of material in the entry window, a double window system was used. The inner flat window was 2±0.05mm thick and the outer dome window was 4±0.05mm thick. The interspace was filled with ^{4}He gas (because of its low neutron absorption properties) at the same pressure as the active volume. The outer dome and structural flange were machined from a single billet of aluminium and the inner flat window was electron beam welded in position with sufficient membrane tension to maintain flatness.

The grid system was of conventional design with two orthogonal cathode grids symmetrically located about the central anode grid. The intergrid spacing was 4±0.02mm. There was an 11mm absorption and drift region associated with each cathode grid. The anode grid was 35µm diameter gold plated tungsten wire with an interwire spacing of 5±0.01mm, and the cathode electrodes were 60µm diameter gold plated tungsten wire also with an interwire spacing of 5±0.01mm. The wires of one cathode grid were parallel to the wires of the anode grid, and were in registration.

The wire grids were wound on transfer frames using a converted lathe. Wire tension was maintained by a flat armature DC motor located on the wire feed assembly, and the torque was controlled by a cam on the winding frame modifying the current to the motor. This system was accurately calibrated and consistently produced grids with wire tension within 1% of the specified value. The wire tension was measured[8] using electrostatic forces between nearby wires both to excite and to detect mechanical oscillation. The wire tension in the anode and cathode grids was 100±1gm wt and 200±1gm wt, respectively. Each wire grid was laid down in turn on an aluminium grid mounting plate and the wires adhered to mounting frames (G10) using epoxy adhesive (Hysol, Dexter Corp USA). The wires were cut from the transfer frame, bent through 90° and a second bead of epoxy applied to reduce the risk of wire pull-through. The mounting frames were secured to the grid mounting plate using epoxy adhesive and all machined surfaces were sealed using the same epoxy material. The wires were electrically connected to tracks on the mounting frames using a conductive epoxy resin (Tra-Duct, Tra-Con Inc USA). The grid mounting plate was then attached to the detector backplate in such a way to reduce the transmission of mechanical deflection of the backplate to the grid mounting plate.

All aspects of grid construction were tested extensively and accurate measurements were made of the geometry. The grid construction and chamber assembly were carried out in a cleanroom.

The eight multipin feedthrough assemblies (Quartex France - modified TMJ 9437A) used to connect the grid wires to the external preamplifiers, were mounted directly on the detector backplate - the conflat knife-edge formed a renewable seal in the aluminium if the torque in the holding bolts was set correctly. The pumping valves and gas purifier flanges were similarly mounted. The front window assembly was sealed to the backplate with double 'O' rings (Buna-N) and there was provision for welding the two sections together if required.

After assembly, the chamber was connected to a gas handling system that incorporated a pumping system for initial evacuation and cleaning, and a gas dosing manifold for filling in a controlled manner. At all stages, the differential pressure between the front and back volumes must be less than 1kPa to eliminate the risk of permanent deformation to the inner flat window. The chamber was heated to 60°C and evacuated until a stable vacuum was obtained (10^{-6} torr). The ^{4}He leakrates for (i) the chamber as a whole, and (ii) the membrane separating the two volumes, were both less than 10^{-10} l torr/sec.

The chamber will be sealed for at least 5 years with no direct monitoring of the gas pressure or purity. Degradation of detector performance will ultimately be a measure of gas pressure and purity. A pump continuously circulates the gas (0.5l/min) through a filter system (UltraPure Inc USA Model C2-84-60-M-SS-250V-B) to maintain gas purity[9]. Contamination, particularly electronegative materials such as oxygen and water, are know to have a major affect on (i) long-term detector performance[10, 11], and (ii) the energy resolution[12].

3. The Electronics

The total charge was collected on the anode grid. A preamplifier (ORTEC Inc USA Model 142IH) capable of accommodating the high capacitance of the grid (600pF) was followed by a main amplifier (ORTEC Inc USA Model 590A) with a shaping time of 2μs. The overall sensitivity was 0.5V/pC and the noise linewidth was 0.2fC (fwhm). The output from a comparator (LeCroy Corp USA MVL407) was used to generate a NIM-logic trigger pulse.

For the wire-by-wire readout system, a total of 256 individual channels was required. Figure 2 is a schematic of a single channel. A charge sensitive low noise preamplifier (LeCroy Corp USA TRA1000) with FET input stage was followed by a passive shaping network (shaping time 2μs) and a main amplifier (National Semiconductor LM6365N). The comparator (LeCroy Corp USA MVL407) provided some noise discrimination and produced ECL signals for all hit wires. The comparator DC level was set for each group of 32 wires under computer control through the readout electronics. The overall sensitivity of the amplifiers was 0.1V/fC and the noise linewidth was 0.4fC which was adequate to handle hit wire signals with minimum gas gain. The signal-to-noise ratio was typically 2:1. The 16 channel preamplifier/amplifier/comparator board was constructed based on a layout developed at the University of Delft[13]. The compact design and relatively low power consumption permitted mounting directly on the backplate of detector, and ECL signals were produced for transmission to the readout electronics located outside the vacuum vessel 4m distant. Particular attention was given to the filtering of DC supplies and EM screening of the sensitive front end electronics.

The channel-to-channel cross-talk, caused primarily by coupling of the main amplifier output into the sensitive front end, was less than 5%. The measured cross-talk was uniform across all the channels tested and introduced no bias into the readout system.

The event processing time was ~10μs due mainly to the length of the output pulses from the comparators. With further developments this processing time will be reduced to meet the maximum design countrate for the whole detector of 10^5 events per second.

4. The Readout Electronics

The Proportional Counter Operating System (PCOS III) (LeCroy Corp USA) was used for event encoding. The ECL signals from the 256 channels were latched in PCOS by time coincidence with the trigger pulse from the anode. The trigger pulse also initiated the address creation with fast encoders sequentially scanning the 256 channels. In order to account for the decision time of the trigger logic, the readout electronics contained a programmable delay (0-0.75μs) for the 256 channels (an independent value for each group of 32 wires).

PCOS was operated in cluster mode where the address of the hit wire and the width of the cluster (in number of hit-wires) were obtained from a centroid calculation. If the cluster width was two hit wires, then the hit wire address was the first value in the sequence with an additional 'half' bit set. This 'half' bit was ignored thereby biasing such events by half a pixel. The maximum width of an event was three with values above this being rejected in software. The encoded information was buffered and transferred by DATABUS (LeCroy High Speed Parallel Bus) and SCSI bus to a UNIX workstation for accumulation and on-line display. An interactive program displayed the raw data as a two dimensional array, and detailed data analysis was provided off-line by a program based on the Interactive Data Language (IDL) package (Research Systems Inc USA).

5. The Performance

Preliminary data from the detector with a test fill of gas (20kPa ^{3}He + 170kPa ^{4}He + 100kPa CF_4) and using a neutron source indicated satisfactory performance. The measured energy resolution (typically 20% fwhm) (refer Figure 3) was adequate to provide discrimination between the thermal neutron peak and the low energy peak due to γ-radiation and electronic noise. The shoulder on the main peak is indicative of an anode region of reduced gas gain. The cause for this is being sought.

Non-linearities in the electronic gain calibration (primarily due to uncertainty in the value of the test input capacitors) for each of the 256 channels must be resolved before the variation in response over the detector active area can be evaluated. Further reduction in non-amplifier-generated noise will improve signal quality and timing coincidence.

The charge collected on the anode as a function of anode-cathode voltage is shown in Figure 4. This indicated that the detector will operate with a gas gain in the range $\times$10-15.

The first pattern from a 64 $\times$ 64 channel sub array (Figure 5) was obtained by placing a mask (shown in outline) between a neutron source and the detector. The missing pixels are caused by poor contacts in an external plug assembly leading to poor readout from associated wires. This may also account, in part, for the low gas gain regions observed in the anode energy spectrum (Figure 3).

6. Conclusions

A large PSD for thermal neutron detection has been successfully constructed to stringent specifications defined by the SANS instrument. The chamber was a significant achievement in design and construction of a large 'pressure vessel' that exhibited minimum deflection under load. The readout electronic system was a cost-effective and versatile method of reading out a low resolution PSD based on a MWPC.

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8. References

[1] P. Convert and J.B. Forsyth (editors). Position-Sensitive Detection of Thermal Neutrons. Academic Press 1983.

[2] R.K. Abele, G.W. Allin, W.T. Clay, C.E. Fowler and M.K. Kopp. IEEE Trans. Nucl. Sci. NS28(1981)811-815.

[3] J.K. Kjems, R. Bauer, B. Breiting and A. Thuesen. IAEA-CN-46(1985)489-493.

[4] B.P. Schoenborn, J. Schefer and D. Schneider. Nucl. Instr. Meth. A252(1986)180-187.

[5] V. Radeka, N.A. Schaknowski, G.C. Smith and B. Yu. in Neutrons in Biology. (B.P. Schoenborn and R.B. Knott editors). Plenum Press 1996 (in press).

[6] R.K. Crawford and J.M. Carpenter. IEEE Trans. Nucl. Sci. NS28(1981)792-799.

[7] J.F. Ziegler, J.P. Biersack and U. Littmark. The Stopping and Range of Ions in Matter. Pergamon Press NY USA 1985.

[8] R.T. Jones. Nucl. Instr. Meth. A269(1988)550-553.

[9] R.A. Boie, J. Fischer, Y. Inagaki, F.C. Merritt, H. Okuno and V. Radeka. Nucl. Instr. Meth. 200(1982)533-545.

[10] J. Va'vra. Nucl. Instr. Meth. A252(1986)547-563.

[11] J.A. Kadyk. Nucl. Instr. Meth. A300(1991)436-479.

[12] B.D. Ramsey, R.F. Elsner and M.C. Weisskopf. Nucl. Instr. Meth. A270(1988)178-184.

[13] P. Coops, C.W.E.-van Eijk and R.W. Hollander. Nucl. Instr. Meth. 227(1984)283-286.

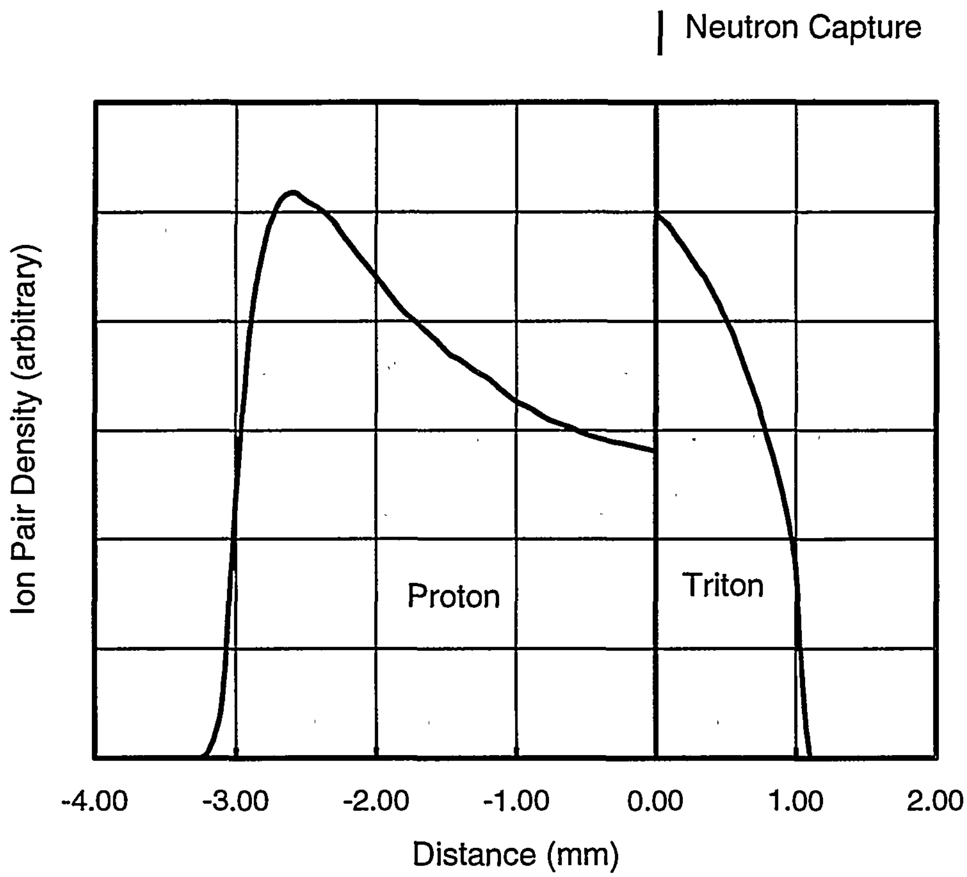

Figure 1.

The calculated charge cloud distribution generated by the capture of a thermal neutron in ^3He gas is plotted for a gas mixture of 190kPa ^3He plus 100kPa CF_4. The spherically averaged projection of this distribution on the anode grid is the primary step in the localisation of the event and impacts on the spatial resolution of the detector.

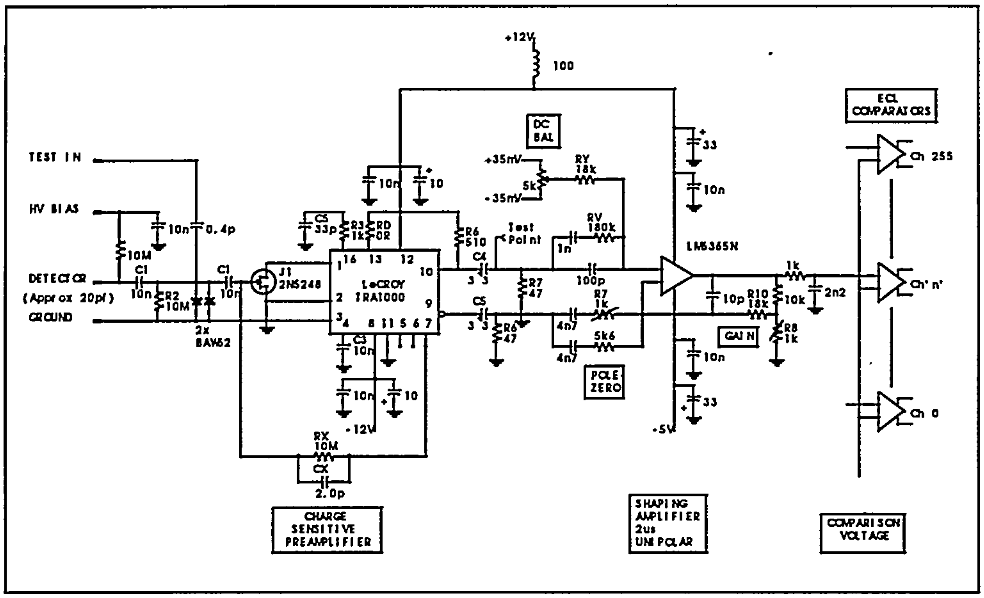

Figure 2

Figure 2.

The circuit diagram is shown of the amplifier/comparator electronics for a single cathode channel. The circuit was an adaptation of that developed at the University of Delft[13], and a commercial design (LeCroy Corp USA Model 2735PC).

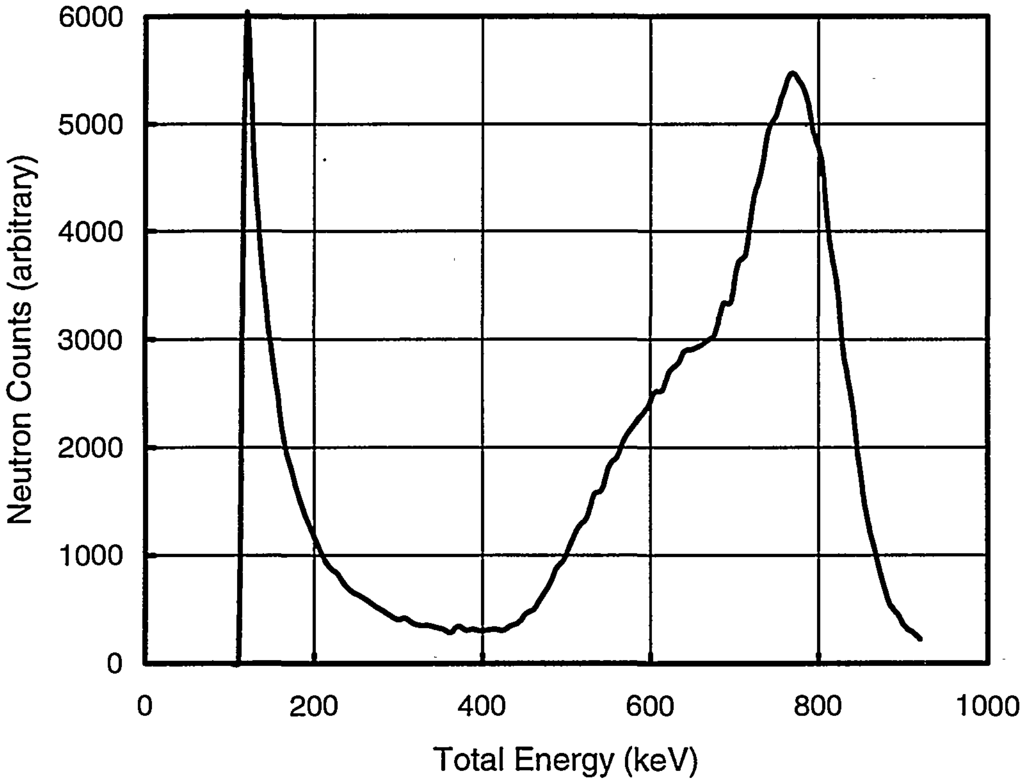

Figure 3.

The measured energy distribution function is plotted for all neutron capture events detected on the anode grid. The low energy discriminator level was set at ~110keV. The anode-cathode high voltage was 2kV, therefore the gas gain was ~14 (refer Figure 4).

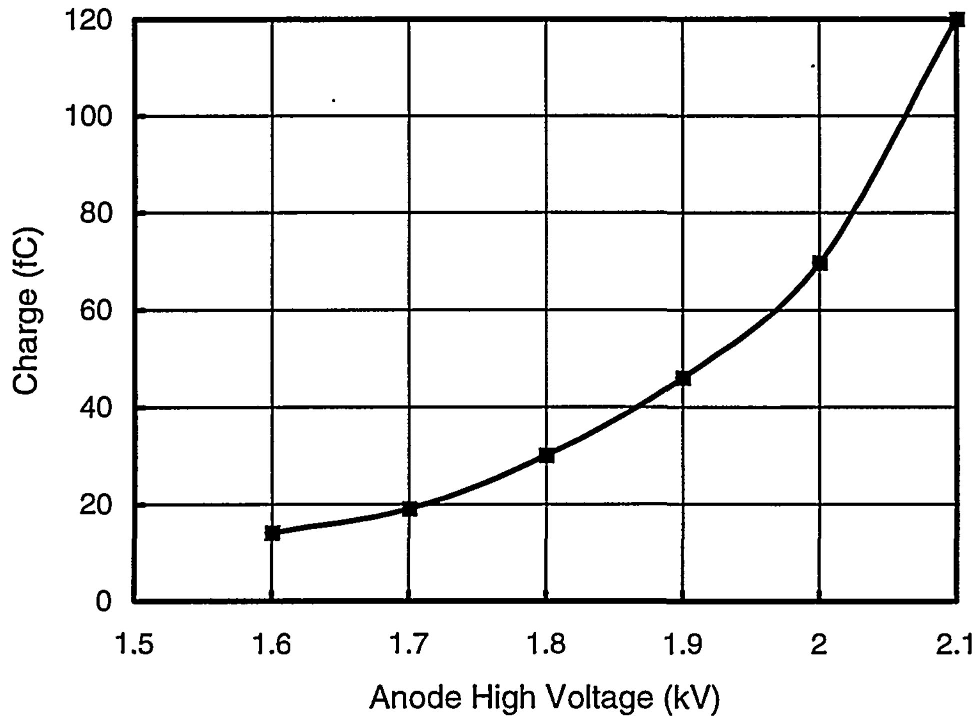

Figure 4.

The total charge collected on the anode is plotted as a function of anode-cathode voltage. The drift field for these measurements was 200V/cm.

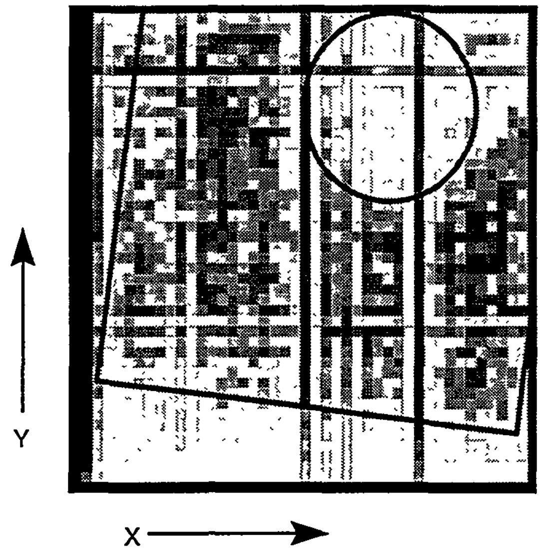

Figure 5.

The first pattern from a 64 x 64 channel sub array of the detector with a test fill of gas (20kPa ^3He + 170kPa ^4He + 100kPa CF_4) was obtained by placing a mask (shown in outline) between a neutron source and the detector. The linear grey scale has 20 levels in the range from 0 (black) to 100 (white). The array size will be increased to the design 128 x 128 channels on completion of the cathode electronic modules. The detection efficiency will be increased by replacing the $^3He/^4He$ gas mixture with pure ^3He gas.