Imaging Brain Tumors Using a Multi-Wire Gamma Camera and Thallium-201

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***Abstract*--Gamma cameras based on multi-wire proportional chambers offer much potential as imaging tools in nuclear medicine. Advantages of these detectors over traditional crystal detectors include superior spatial resolution, higher count rate capabilities, portability and low cost.**

We have developed a gamma camera based on a multi-wire proportional chamber equipped with a high rate, digital electronic read-out system for imaging applications in nuclear medicine. The complete, highly transportable system has been demonstrated to operate reliably and with predictable accuracy in a hospital environment. The camera demonstrates an intrinsic spatial resolution of 1.27mm and a maximum count rate capability of 1 million cps.

Thallium-201 is a radioisotope with a strong affinity for viable tumor tissue owing to its potassium like characteristics. There is substantial uptake in primary and metastatic cerebral tumors with little uptake in the normal brain. It is ideally suited for imaging with a multi-wire proportional chamber due to its relatively low energy photon emission.

The gamma camera has been used to image Thallium-201 labeled brain tumors in patients undergoing treatment in order to detect recurrent or residual tumor. The results and images obtained demonstrate the great potential of the gamma camera in the field of neuro-oncology.

We present some design features of the camera and results obtained from measurements carried out to assess its performance characteristics. Clinical images obtained using the camera will also be presented.

I. Introduction

The main advantage of radioisotope techniques in tumor imaging is their ability to monitor tumor metabolism and growth. Metabolic sensitive, radioisotope methods give information on tumor physiology helping in the differential diagnosis between benign and malignant disease and detecting early changes following treatment such as radiotherapy or chemotherapy more reliably than anatomical imaging techniques such as CT, ultrasound or MRI.

The detection and localization of a tumor by radioisotope techniques depend upon the observation of different concentrations of radioactivity in the tumor tissue and in the surrounding tissue.

In order to detect changes in a tumors growth and appearance, a gamma camera designed for use in this field should demonstrate good spatial resolution in order to distinguish fine features in the image and a high count rate capability in order to provide high count statistics for accurate tumor quantification. The multi-wire proportional chamber (MWPC), a radiation detector used in particle physics since its introduction in the nineteen-sixties, demonstrates such properties, giving it enormous potential as an imaging tool in oncology [1-2].

We have recently developed a gamma camera based on a pressurized, xenon filled, multi-wire proportional chamber [3]. More recently this camera has been used to take pictures of brain tumor patients injected with Thallium-201.

II. The Use of Thallium-201 in Diagnostic Oncology

Thallium-201 is a radioisotope with a strong affinity for viable tumor tissue owing to its potassium-like biological characteristics. Like potassium it is accumulated intracellularly by the ATP-dependent sodium potassium pump. Thallium-201 accumulation is related to growth rate; increased uptake occurs in rapidly growing tissue while little uptake is seen in growing tissue [4-5]. As a result there is substantial uptake in primary and metastatic cerebral tumors with little uptake in the normal brain. It is suitable for human use since it is rapidly cleared from the blood and the critical organ dose is low

Thallium-201 has found widespread use in nuclear medicine over the last two decades. It is cyclotron produced from Thallium-203, has a half-life of 73 hours and emits primarily photons in the energy range 70-80keV. The relatively, low energy photon emission of Thallium-201 makes it ideal for imaging by a gas filled multi-wire proportional chamber.

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III. DESCRIPTION OF THE CAMERA

The gamma camera has been previously reported [3]. The basic design of the MWPC is shown in Figure 1 and the physical characteristics are summarized in Table I. The detector can be divided into 2 zones; a drift zone defined by the drift cathode and a plane of wires at negative potential called a grid, and an amplification zone defined by the grid, a plane of uniformly spaced anode wires and a plane of cathode strips. The cathode strips and the grid wires are shown in the photograph in Figure 2. Signals are read from the anode wires and the cathode strips which are orientated perpendicularly to one another in order to enable bi-dimensional reading. The sensitive area of the camera is 250 mm by 250 mm.

TABLE I
DETECTOR PHYSICAL CHARACTERISTICS

Sensitive area	250mm x 250 mm
Drift length	52 mm
Anode-grid gap	3.00 mm
Anode-cathode strips gap	1.00 mm
Anode wire pitch	1.27 mm
Grid wire pitch	1.27 mm
Cathode strip separation	0.08 mm
Cathode strip width	1.10 mm
Anode wire diameter	20 µm
Gas Mixture	xenon (90%) - ethane (10%)

The detector is equipped with a digital electronic system capable of processing events up to speeds of 5 MHz. Charge signals collected on the anode wires and the cathode strips are individually amplified and shaped before passing through a discriminator with a programmable threshold, which emits a digital pulse if the amplitude of the signal exceeds the threshold. The distribution of the pulses across the channels is then analyzed. If a cluster of pulses is spread over three or less adjacent channels in each direction, the cluster is accepted. Then if the accepted cluster of pulses from the wires and the accepted cluster of pulses strips both occur within a specified time window, the event is accepted as a hit and an X and Y address is determined. In the case of three adjacent channels being hit, the central channel defines the address, in the case of 2 channels being hit, the address alternates between an even and an odd channel number. The reconstructed image has an area of 192 x 192 pixels with each pixel having an area of 1.27 mm x 1.27 mm.

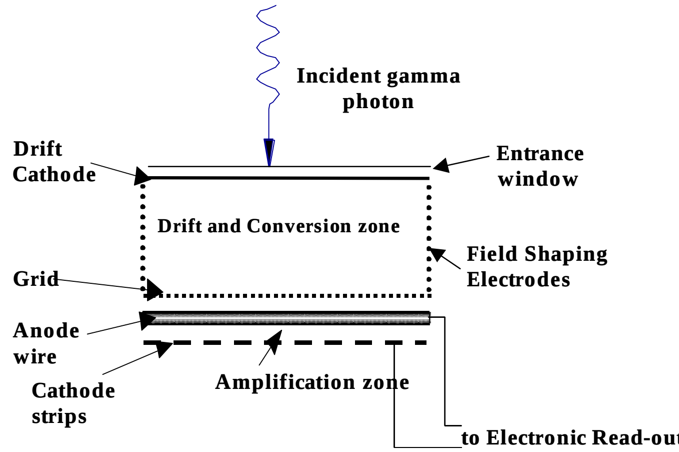

Fig. 1. Layout of detector.

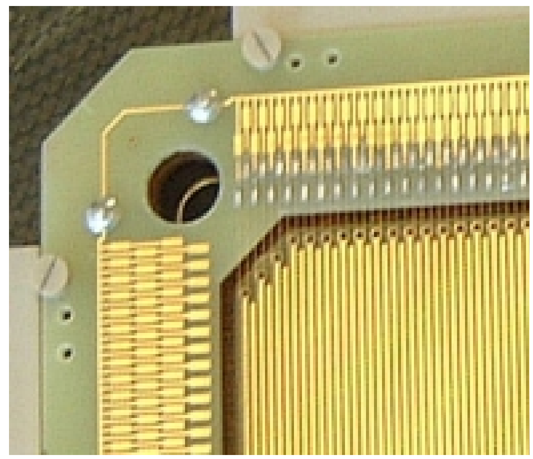

Fig. 2 Photograph of grid wires and strips inside detector

IV. SPATIAL RESOLUTION AND SENSITIVITY

In imaging applications one of the most important performance characteristics is the spatial resolution. The following measurements were carried out at an operating pressure of 5 bar. The intrinsic spatial resolution of the detector was determined by irradiating the detector with a Thallium-201 source, along a narrow line of width <1mm. The resulting line spread function when the line source, is placed parallel to the wires is shown in Figure 3. It can be seen that the FWHM is one wire pitch, defining the intrinsic spatial resolution to be 1.27 mm. The resolution in this case is limited by the wire spacing due to the method of electronic processing used. The spatial resolution and spatial linearity were further investigated using bar phantoms. The surface of the detector was irradiated through a lead bar phantom with spacings from 4.0mm to 2.5mm. The resulting image is shown in Figure 4.

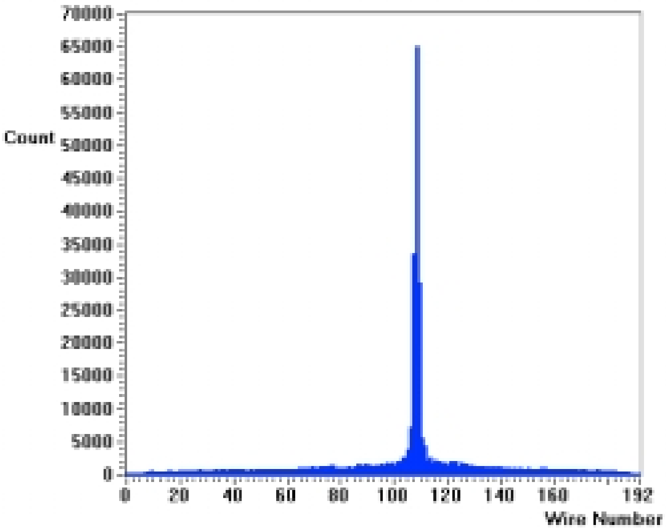

Fig. 3. Line spread function for Thallium-201 demonstrating an intrinsic spatial resolution of 1.27mm

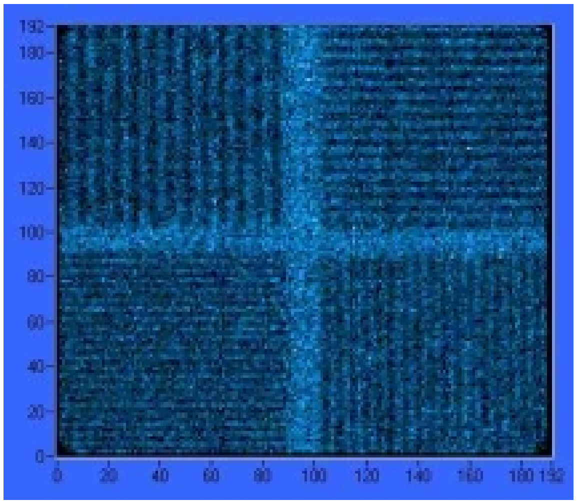

Fig. 4. Image of bar phantom with 4mm, 3.5mm, 3mm and 2.5mm line spacings

The sensitivity of the camera operated at 5 bar to Thallium-201 was measured using different collimators – Low Energy High Sensitivity (LEHS), Low Energy All Purpose (LEAP) and Low Energy High Resolution (LEHR). The results are summarized in Table 2. The linearity of the count rate is shown in Figure 5 where the count rate has been measured for different activities of Thallium-201 using the LEHS collimator.

TABLE II
CAMERA SENSITIVITY TO THALLIUM-201

Collimator	Sensitivity (cps/MBq)
LEHS	333
LEAP	143
LEHR	95

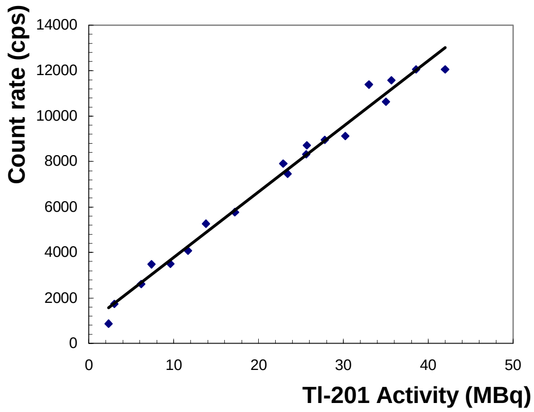

Fig. 5. Relationship between the count rate of the camera and the activity of Thallium-201 being imaged.

V. Preliminary Clinical Studies

The preliminary clinical studies were carried out at the department of Nuclear Medicine in the Queen Elizabeth Hospital, Birmingham, UK. Patients were injected with approximately 100MBq of Thallium-201 for their standard, scheduled SPECT brain scan carried out using a standard Anger camera. After this examination the patients were asked to sit in front of the multi-wire gamma camera and imaged from three projections – posterior, right lateral and left lateral. These images were then compared with the equivalent raw projection images of the same patient taken minutes previously with the Anger camera.

Figure 6 is an example of a set of images taken of a patient who had been operated on for a Grade 2 glioma tumor in 1999. As can be seen from the images there is no significant uptake in the brain area apart from the natural uptake around the mouth and the nasal area. This would indicate that there was no tumor recurrence and is in agreement with the Anger scans shown in Figure 7. There are some noticeable differences in the characteristics of the images from the two cameras.

The pixel size of the multi-wire gamma camera images is smaller 1.27 mm x 1.27 mm which gives a finer resolution compared to the Anger camera which has pixels of size 3.20 mm by 3.20 mm

In addition the count rate during image acquisition was significantly higher for the multi-wire gamma camera at 1300 cps compared to 300 cps for the Anger gamma camera. This was mainly because a LEHS collimator was used with the multi-wire gamma camera while a LEHR collimator was used with the Anger camera. Figure 8 shows a right lateral image taken of a patient before undergoing treatment. The area of increased uptake corresponding to a frontal tumor can be clearly see while an area of low uptake which corresponds to an area of infarct is also visible.

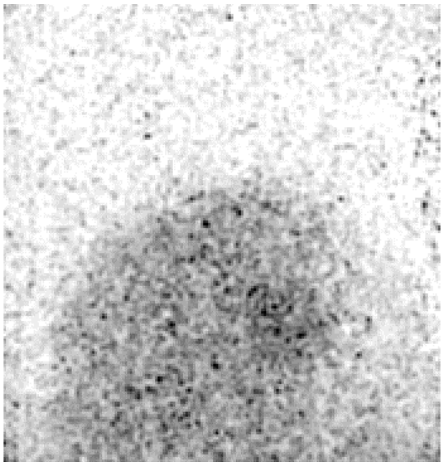

Fig. 8. Planar lateral view of brain showing an area of increased uptake corresponding to a tumor and an area of extremely low uptake corresponding to damaged brain tissue

VI. Conclusion

We have described the use of a gamma camera based on a xenon-filled multi-wire proportional chamber as an imaging tool in oncology.

The detector provides an intrinsic spatial resolution of 1.27 mm and a high sensitivity to low energy radioisotopes when operated at a pressure of 5 bar. Preliminary clinical trials have shown the potential of the camera system for the detection and localization of brain tumors labeled with Thallium-201. This type of gamma camera could offer a low cost high-resolution alternative to the standard Anger camera in low-energy radioisotope imaging applications.

VII. Acknowledgement

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VIII. References

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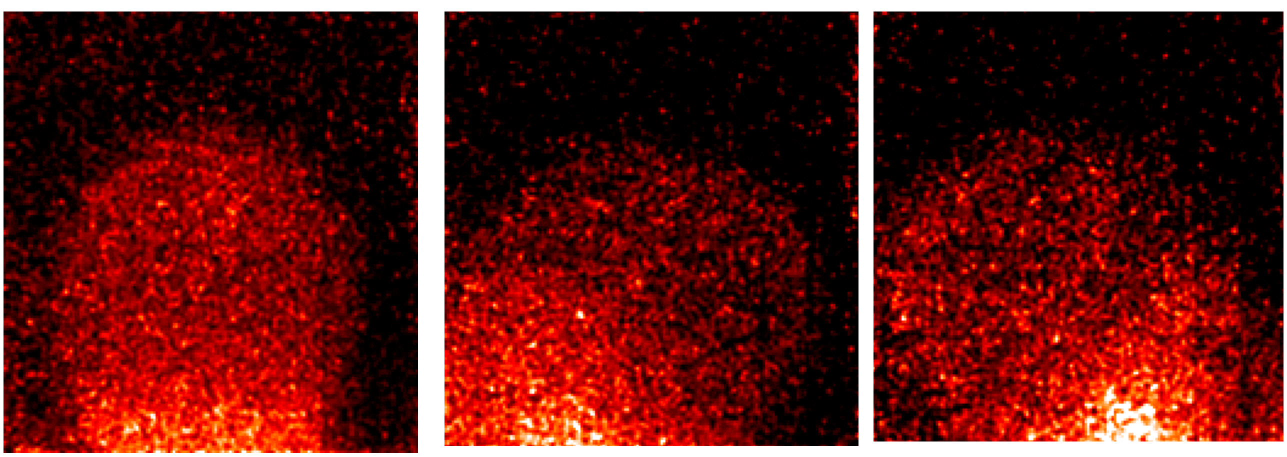
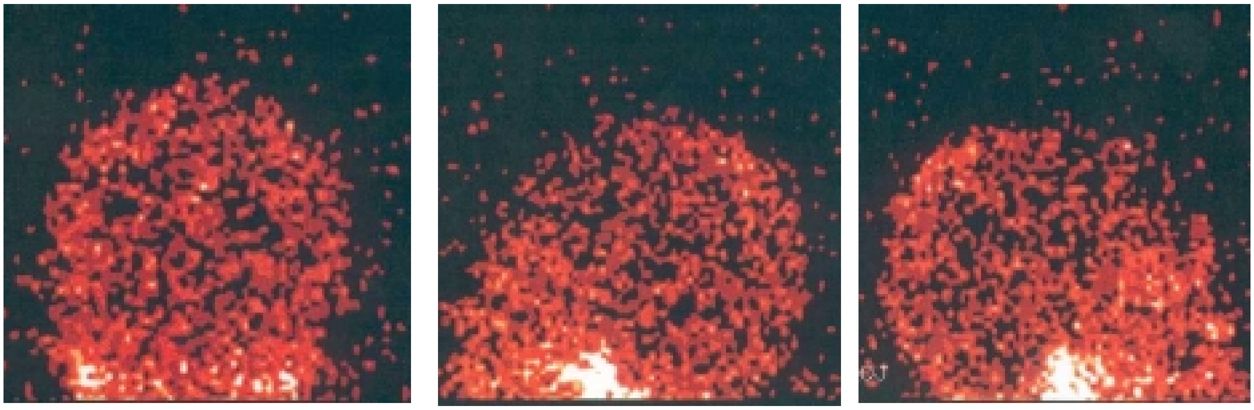


a) b) c)

Fig. 6. Planar views of brain in patient undergoing treatment taken with multi-wire gamma camera – no tumor regrowth is detected a) posterior view, b)left lateral view and c) right lateral view. The pixel size is 1.27mm x 1.27mm



a) b) c)

Fig. 7. Planar views of brain in patient undergoing treatment taken with standard anger gamma camera – no tumor regrowth is detected a) posterior view, b)left lateral view and c) right lateral view. The pixel size is 3.20 mm x 3.20 mm