Potential Advantages of a Cesium Fluoride Scintillator for a Time-of-Flight Positron Camera

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In order to improve the quality of positron tomographic imaging, a time-of-flight technique combined with a classical reconstruction method has been investigated. The decay time of NaI(Tl) and bismuth germanate (BGO) scintillators is too long for this application, and efficiency of the plastic scintillators is too low. Cesium fluoride appears to be a very promising detector material.

This paper presents preliminary results obtained with a time-of-flight technique using CsF scintillators. The expected advantages were realized.

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TIME-OF-FLIGHT

The time-coincidence technique in positron cameras allows the determination of the direction of each event by detecting the two 511-keV annihilation photons emitted 180° apart with two opposing banks of detectors. The advantages of that "electronic" collimation have been emphasized by different groups (*1*).

In a classical positron camera the coincidence resolving time is ~10–20 nsec. Thus each event is back-projected over the whole size of the image, which involves poorer image contrast. Furthermore, the ratio of random to true coincidences is not negligible and this also contributes in reducing the image contrast.

G. Brownell (*2*) proposed a time-of-flight system for three-dimensional positron imaging. A timing resolution of about 400 psec was obtained with plastic scintillators. More recently, Dunn (*3*) used the same technique to localize directly each emitting source—without further mathematical data processing—by measuring the time interval between the arrival of the two photons at the opposed detectors. A time fluctuation of 180 psec (FWHM) (corresponding to a spatial resolution of 2.7 cm) was obtained with very fast plastic scintillators and phototubes and by adjustment of the energy threshold to 300 keV. Unfortunately, in both cases, the detection efficiency of plastic scintillators is about one third of that for NaI(Tl), therefore one ninth for a coincidence technique. Furthermore, an energy threshold adjusted to 300 keV results in a low percentage of detected events. This poor sensitivity is a major disadvantage in a clinical instrument, since the short-lived positron emitters contraindicate a long exposure time.

PROPOSED METHOD

The proposed method consists of combining the advantages of the high efficiency of inorganic scintillators with those of the time-of-flight technique. In using a time coincidence much shorter than those corresponding to the transit time of a photon in the object, a spatial distribution of each event can be determined in order to back-project the information with a reconstruction method on a length only a fraction of the size of the image.

For this purpose, a mathematical simulation was carried out and showed that the image signal-to-noise ratio is greatly improved by using such a technique. This ratio is defined as $S/N = A^2/\sigma^2$ where A is the true activity in each pixel and σ is the standard deviation of the measured activity distribution at same point (*4*). For instance, for a 0.5-nsec coincidence resolving time (FWHM), the signal-to-noise ratio is about 2.9 times

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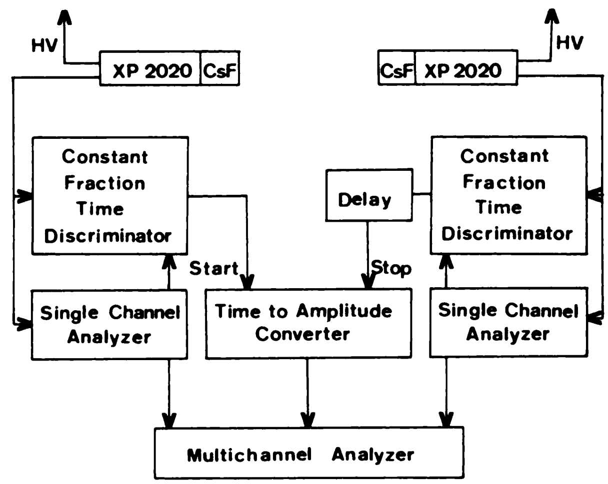

FIG. 1. Timing circuit block diagram.

that obtained with the classical reconstruction technique, in the case of a uniform phantom 32 cm in diameter. This means that to obtain the same image quality without the time-of-flight technique, one would need 8.5 times the number of counts.

EXPERIMENTATION

The block diagram of the timing apparatus is shown on the Fig. 1. The two phototubes are XP 2020, 2 in. in diameter.* The energy threshold is adjusted to 100 keV. We developed circuits for a constant-fraction time discriminator and a fast time-to-amplitude converter for this application. Energy spectra and time distributions are visualized on a single-channel analyzer. The positron emitter is a 12-μCi Na-22 source.

RESULTS AND DISCUSSION

The main results are summarized in Table 1. It shows the following.

1. The energy resolution is better for NaI(Tl) than for CsF. But, indeed, this is not a disadvantage for CsF because the energy selection would involve an important loss of sensitivity (about 60%). From this point of view, it appears that bismuth germanate (BGO) is the most suitable scintillator because of its high stopping power. Thus the photopeak fraction could be selected without appreciable loss of sensitivity in order to reject radiation scattered in the object.
2. The detection efficiency is another important parameter for the choice of a detector. BGO appears to be the first choice and CsF a little better than NaI(Tl). From this point of view, plastics are unsuitable for medical positron imaging.
3. The fast decay time of CsF permits adjustment of the resolving time to the size of the organ, which would not be possible with BGO or NaI(Tl). Thus, a higher fraction of random coincidence events can be rejected, providing better image contrast. Furthermore, the counting-rate capability is higher with CsF than with NaI(Tl) or BGO. That characteristic is of great importance in dynamic studies with short-lived positron emitters.

TABLE 1. COMPARISON BETWEEN NaI(Tl), $Bi_4Ge_3O_{12}$, CsF, AND Ne-104

	NaI(Tl)	$Bi_4Ge_3O_{12}$	CsF	Ne-104	
Density	3.67	7.13	4.61	1.03	
Atomic numbers	11, 53	83, 32, 8	55, 9	1, 6	
Linear attenuation coefficient at 511 keV (cm^{-1})	0.34	0.92	0.39		
Scintillation peak wavelength nm	413	480	390	406	
Index of refraction at peak wavelength	1.78	2.15	1.48	1.58	
Dimensions of the crystals: diameter and height	1¼″ × 1″	⅘″ × 1¼″	1″ × 1″	1¼″ × 1″	
Relative scintillation output(%)	100	8	3.7	29	Measurements with a Na-22 planar source 12 μCi, two opposing XP2020 and 20-mm diameter collimator
Energy resolution at 511 keV(%)	10	25	35	no photoelectric effect	
Scintillation decay time (nsec)	230	300	5	2, 0	
Coincidence resolving time (FWHM) for a 100-keV threshold (nsec)	2.0	3.4	0.55	0.52	
Relative single counting rate (%) for the same volume of scintillator	100	178	118	13	
Photopeak fraction	0.3	0.8	0.3		

4. The resolving time of CsF is much shorter than those of NaI(Tl) and BGO. It is the only scintillator that allows the use of the time-of-flight technique in a positron camera. The expected advantages are based on the results of our mathematical simulation and on our tests of resolving time (about 0.6 nsec FWHM).

In conclusion, CsF appears to be the most suitable scintillator for the design of a high-resolving-time positron camera.

FOOTNOTE

* Radiotechnique, Compelec.

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