Title

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INTRODUCTION

Primary considerations for the design of positron emission tomographs for medical studies in humans are high imaging sensitivity, whole organ coverage, good spatial resolution, high maximum data rates, a minimum of mechanical motion, good shielding against out of plane activity, good pulse height discrimination against scattered photons, and good timing discrimination against accidental coincidences.

DETECTORS

Table 1 lists the three detector materials used in positron tomographs, NaI(Tl), CsF, and bismuth germanate (BGO). NaI(Tl) leads in photon yield and pulse height resolution, CsF leads in speed, and BGO leads in detection efficiency. An "ideal detector" with the best properties of all three would be very useful.

Table 1. PROPERTIES OF DETECTOR MATERIALS

Material	NaI(Tl)	CsF	BGO	"ideal Detector"
Density (gm/cm^3)	3.67	4.61	7.13	>6
Atomic Numbers	11,53	55,9	83,32,8	>80
Hygroscopic?	YES	VERY	NO	NO
Photoelectron Yield (511 keV)	2,500	100	300	>1,000
Scintillation decay time (nsec)	230	5	300	<10
Photoelectrons/nsec	11	20	1	>100
Time resolution (FWHM nsec)	1.5	0.4	7	<0.2
Energy resolution (% FWHM)	7	30	12	<8

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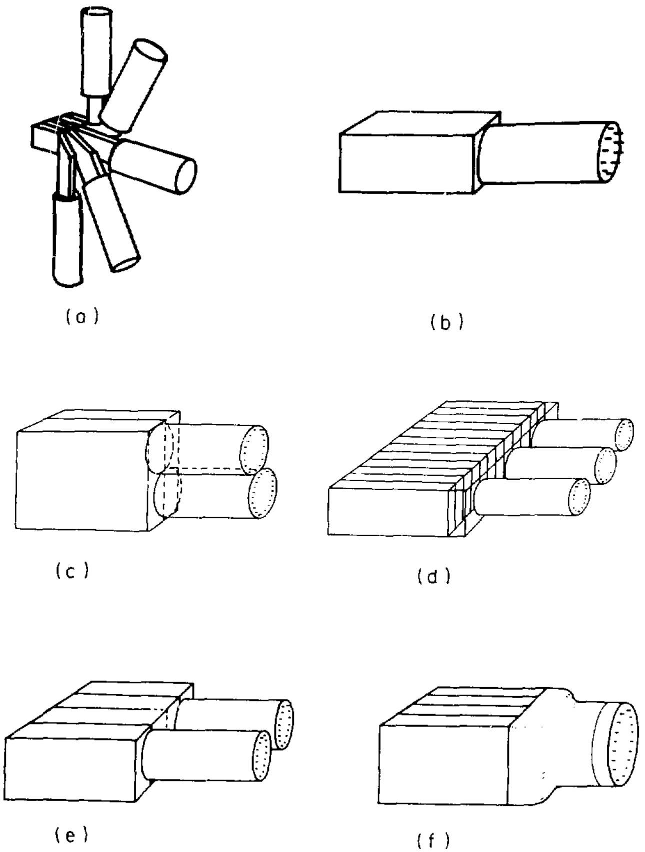

Figure 1: Several crystal-phototube coupling schemes. See text.

The Donner 280-Crystal Positron Tomograph uses 10 mm wide BGO crystals coupled to 40 mm PMTs but this coupling scheme is limited to one ring (Fig. 1a).[1] Many systems use square or cylindrical crystals coupled directly to a PMT (Fig. 1b) but the crystal size is limited to the size of the PMT ($\geq$14mm).[2,3,4,5] Fig. 1c shows the coupling of crystals one-half the width of the PMT. It is used in the NIH Neuro PET (10 mm crystals) and is the basis for a new multi-ring design at Donner Laboratory (7 mm crystals). Other approaches include the use of Anger position logic[6] (Fig. 1d), coded coupling logic (Fig. 1e), and special multi-anode PMTs (Fig. 1f).

The use of fast detectors, such as CsF or plastic, is being explored for the localization of the annihilation point by time-of-flight.[7,8,9,10] This approach can be used to reduce the statistical noise in the reconstructed images.

SAMPLING

A stationary detector ring (Fig. 2a) has the capability for rapid sequence imaging, but it cannot achieve the intrinsic resolution of the detectors because of insufficient linear sampling. Approaches to overcome this limitation include scan-rotate motion[11,12,13,14] (Fig. 2b), circular "wobble" motion[15,16,12] (Fig. 2c), "Positology"- rotation of a circular array of non-uniformly spaced detectors[17,18] (Fig. 2d), "Dichotomic"- rotation of half-rings about the center[19] (Fig. 2e), and "Clamshell"- hinging half-rings about the circumference[20] (Fig. 2f).

Other resolution factors include (1) positron range,[21] (2) deviations from 180° emission,[22] (3) detector penetration,[1,23] (4) the reconstruction filter, (5) organ motion, and (6) tracer motion due to flow or metabolism.

SHIELDING AND BACKGROUNDS

The primary backgrounds in positron emission tomography are accidental coincidences of unrelated annihilation photons and true coincidences of photon pairs where one or both have scattered.[24] Both are reduced by using lead shielding and by time and pulse height discrimination.[1,25,26,27]

ELECTRONICS

The primary components include (1) timing and pulse height discriminators, (2) coincidence and address circuits, (3) memory, (4) filtering and back-projection circuits, and (5) display.

CONCLUSIONS

Although positron emission tomography is used in many research centers around the world, the instrumentation can be improved in several ways. These include the use of larger numbers of small, efficient detectors closely packed in many rings, the development of new detector materials, and novel electronic designs to reduce the deadtime and increase maximum event rates.

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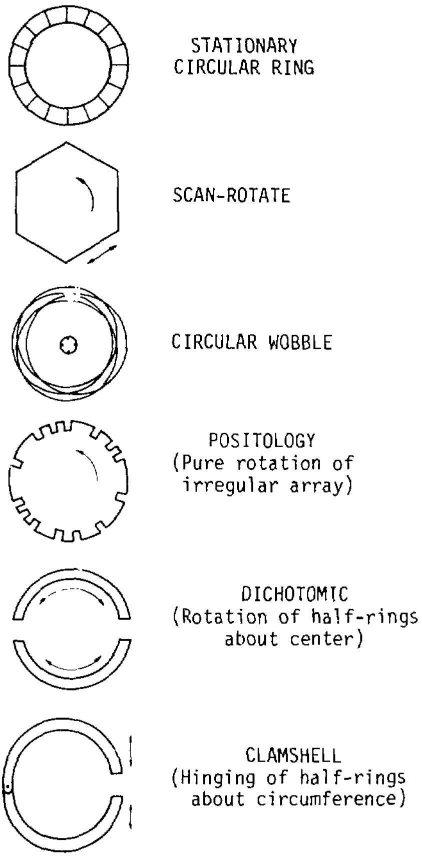

Figure 2: Several sampling schemes for positron tomography.

REFERENCES

1. Derenzo SE, Budinger TF, Huesman, RH, et al: Imaging properties of a positron tomograph with 280 BGO crystals. IEEE Trans Nucl Sci NS-28: No 1, 81-89, 1981

2. Burnham CA and Brownell GL: A multi-crystal positron camera. IEEE Trans Nucl Sci NS-19: No 3, 201-205, 1972

3. Cho ZH, Chan JK, and Eriksson L: Circular ring transverse axial positron camera for 3-dimensional reconstruction of radionuclides distribution. IEEE Trans Nucl Sci NS-23: No 1, 613-622, 1976

4. Hoffman EJ, Phelps ME, Huang SC, et al: A new tomograph for quantitative positron emission computed tomography of the brain. IEEE Trans Nucl Sci NS-28: No. 1, 99-103, 1981

5. Tanaka M, Hirose Y, Koga K, et al: Engineering aspects of a hybrid emission computed tomograph. IEEE Trans Nucl Sci NS-28: No. 1, 137-147, 1981

6. Burnham C, Bradshaw J, Kaufman D, et al: One dimensional scintillation cameras for positron ECT ring detectors. IEEE Trans Nucl Sci NS-28: No. 1, 109-113, 1981

7. Allemand R, Gresset C, and Vacher J: Potential advantages of a Cesium Fluoride scintillator for a time-of-flight positron camera. J Nucl Med 21: 153-155, 1980

8. Mullani NA, Ficke DC, Hartz R, et al: System design of fast PET scanners utilizing time-of-flight. IEEE Trans Nucl Sci NS-28: No. 1, 104-107, 1981

9. Nickles RJ, Hichwa RD and Hutchins GD: Time-of-flight sampling of arterial concentrations of positron-emitters. J Nucl Med 22: P39, 1981 (Abstract)

10. Ter-Pogossian MM, Mullani NA, Ficke DC, et al: Photon time-of-flight-assisted positron emission tomography. J Comput Assist Tomogr 5: 227-239, 1981

11. Phelps ME, Hoffman EJ, Mullani NA, et al: Application of annihilation coincidence detection to transaxial reconstruction tomography. J Nucl Med 16: 210-224, 1975

12. Mullani NA, Ter-Pogossian MM, Higgins CS et al: Engineering aspects of PETT V. IEEE Trans Nucl Sci NS-26: No 2, 2703-2706, 1979

13. Ter-Pogossian MM, Mullani NA, Hood J, et al: A multislice positron emission computed tomograph (PETT IV) yielding transverse and longitudinal images. Radiology 128: 477-484, 1978

14. Williams CW, Crabtree MC, and Burgiss SG: Design and performance characteristics of a positron emission computed axial tomograph-- ECAT-II. IEEE Trans Nucl Sci NS-26: No 1, 619-627, 1979

15. Bohm C, Eriksson L, Bergstrom M, et al: A computer assisted ring detector positron camera system for reconstruction tomography of the brain. IEEE Trans Nucl Sci NS-25: No 1, 624-637, 1978

16. Brooks RA, Sank VJ, Talbert AJ, et al: Sampling requirements and detector motion for positron emission tomography. IEEE Trans Nucl Sci NS-26: No 2, 2760-2763, 1979

17. Tanaka E, Nohara N, Yamamoto M, et al: "Positology" - the search for suitable detector arrangements for a positron ECT with continuous rotation. IEEE Trans Nucl Sci NS-26: No 2, 2728-2731, 1979

18. Nohara N, Tanaka E, Tomitani T, et al: Positologica: A positron ECT device with a continuously rotating detector ring. IEEE Trans Nucl Sci NS-27: No 3, 1128-1136, 1980

19. Cho ZH, Hong KS, Ra JB, et al: A new sampling scheme for the ring positron camera- dichotomic ring sampling. IEEE Trans Nucl Sci NS-28: No 1, 94-98, 1981

20. Huesman RH, Derenzo SE, Gullberg GT, and Budinger TF: Novel two-position sampling scheme for dynamic positron emission tomography. J Nucl Med 22: P38-P39, 1981 (Abstract)

21. Derenzo S: Precision measurement of annihilation point spread distributions for medically important positron emitters. In Proceedings of the 5th International Conference on Positron Annihilation, Sendai, Japan, The Japan Institute of Metals, 1979, pp 819,823

22. Colombino P, Fiscella B, Trossi L: Study of positronium in water and ice from 22 to -144 °C by annihilation quantum measurements. Nuovo Cimento 38: 707-723, 1965

23. Derenzo SE: Monte Carlo calculations of the detection efficiency of arrays of NaI(Tl), BGO, CsF, Ge, and plastic detectors for 511 keV photons. IEEE Trans Nucl Sci NS-28: No. 1, 131-136, 1981

24. Derenzo SE, Zaklad H, and Budinger TF: Analytical study of a high-resolution positron ring detector system for transaxial reconstruction tomography. J Nucl Med 16: 1166-1173, 1975

25. Atkins FB, Harper PV, Scott R, et al: Analysis of coincident scatter for positron cameras using large area detectors. J Nucl Med 20: 635, 1979 (Abstract)

26. Derenzo S: Method for optimizing side shielding in positron emission tomographs and for comparing detector materials. J Nucl Med 21: 971-977, 1980

27. Derenzo SE, Budinger TF, Cahoon JL, Huesman RH, and Jackson HG: High resolution computed tomography of positron emitters. IEEE Trans Nucl Sci NS-24: No 1, 544-558, 1977