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DETECTORS, SAMPLING, SHIELDING, AND ELECTRONICS FOR POSITRON EMISSION TOMOGRAPHY

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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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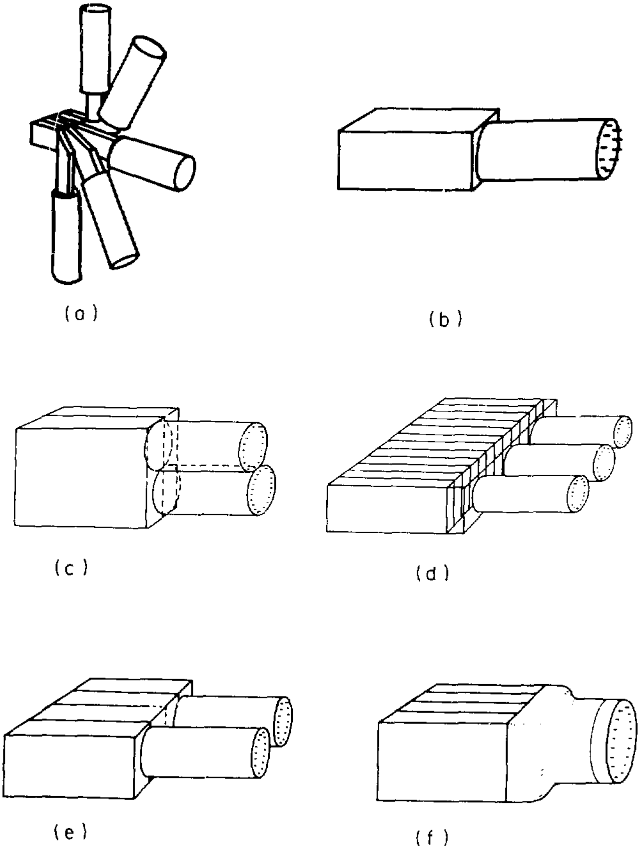

Figure 1: Several crystal-phototube coupling schemes. See text.

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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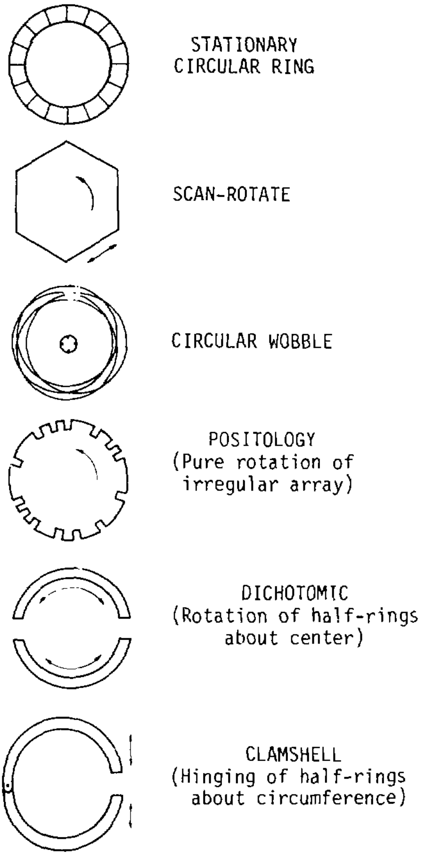

Figure 2: Several sampling schemes for positron tomography.

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