NOMENCLATURE FOR FOURIER TRANSFORMS OF SPREAD FUNCTIONS OF IMAGING SYSTEMS USED IN NUCLEAR MEDICINE

Although many important differences exist between imaging processes in optics, radiology, and nuclear medicine, it is probably advantageous to adopt standard terms and symbols for the most important analogous concepts used to describe these processes. While it is recognized that analogies are always imperfect and the definition of terms is quite arbitrary, the consistent use of standard terms and symbols may facilitate communication between workers across these fields. Since optics was developed first, we might expect to find guidance to suitable concepts and nomenclature there.

In recent years, however, workers in optics have made increasing use of concepts and methods of linear systems analysis which have been most intensively developed and extensively used in electronics and communication theory (*1–6*). In particular, a very fruitful analogy has been drawn between *impulse response* (used to describe the output of an electronic system for a very short input pulse) and the (*point* or *line*) *spread function* (used to describe the shape of the image formed by an optical system of a point or line object element). In addition, the Fourier transform (FT) of the *impulse response,* usually called the *transfer function,* is analogous to the FT of the *spread function* which is called the *optical transfer function.* The latter concepts are extremely useful since the *transfer function* describes the temporal frequency response of an electronic system and the *optical transfer function* describes the analogous spatial frequency response* of an optical system. The *optical transfer function* may in general have complex values. Its modulus, or absolute value, is called the *modulation transfer function*†, and its argument is called the *phase transfer function.*

The important step of standardizing these terms in optics was taken in 1961 when Ingelstam (*9*), as Chairman of the Subcommittee for Image Assessment Problems of the International Commission of Optics, published recommendations for nomenclature which have subsequently been widely adopted. Before that publication (and to some extent, since) different writers (*10–12*) have used a variety of terms in place of *optical transfer function* such as *sine-wave response, spatial frequency response, complex transfer function, contrast transfer function, modulation transfer function,* etc.

Although the radiographic process for imaging x-ray distributions with screen-film systems is not based on such optical phenomena as diffraction or refraction, the term *optical transfer function* has nevertheless been used increasingly in radiology to denote the FT of the *spread function* of radiographic imaging systems. Also in radiology, as in optics, most writers have used the terms *modulation transfer function* and *phase transfer function* to refer to the absolute value and argument, respectively, of the *optical transfer function.*

In nuclear medicine, following Beck (*13–15*), the term "modulation transfer function"* has been used most frequently to designate the FT of the *spread function*† of radionuclide imaging systems, and this has resulted in some confusion among those familiar with the standard usage of this term in optics and radiology. To be consistent with those fields, we in nuclear medicine would refer to the FT of a (*point* or *line*) *spread function* as an *optical transfer function,* and to minimize confusion across these fields, it has been suggested (*16*) that this possibility be considered seriously.

The informal responses to this suggestion can be described most politely as covering the range from unenthusiastic to politely unenthusiastic. This is attributed to the fact that, since the term "optical transfer function" would convey meaning only by virtue of the formal analogy to its definition in optics, the use of this term in nuclear medicine appears undesirable. Thus while it is generally agreed that the FT of a *spread function* is of fundamental importance in every imaging field, the question of a suitable term for this function for the imaging sys-

* The object elements in this case are light intensity distributions which vary spatially in a sinusoidal manner. Although the notion of describing an optical system in terms of its spatial frequency response can be traced back almost 100 years to Abbe's (*7*) theory of the microscope, this approach has been developed most intensively during the past 25 years following Duffieux (*8*).

† Thus the *modulation transfer function* is always real, with positive or zero values, by this definition.

* The rationale for this definition has been expressed most succinctly by Linfoot (*12*). When the *spread function* is symmetric "it is then more convenient to take α (the angle of phase shift) always zero and to allow M (the modulation transfer function) to assume negative values." Unlike the situation in optics, *spread functions* for radionuclide scanners are almost always symmetric, and for scintillation cameras, very nearly so. The FT of symmetric *spread functions* is always real. In this case, there is little need for additional terms to describe the modulus and argument.

† The response to a point (or line) source of unit intensity is called the *point* (or *line*) *source response function* (*13*). When this function is normalized to unit total response, it is called the *point* (or *line*) *spread function,* which characterizes the spatial resolution, but not the sensitivity, of the imaging system.

terms used in nuclear medicine has not yet been answered satisfactorily.

From among the many alternatives that exist, it appears desirable to select terms that are general enough to associate analogous concepts in all imaging fields, yet specific enough to designate a particular system or component appropriately.

On the most general level, the terms *system spread function** and *system transfer function* appear satisfactory. For systems that are linear and stationary (*1–6*), these functions are related by the FT and its inverse, FT^{-1}; thus

$$\textit{system spread function} \underset{FT^{-1}}{\overset{FT}{\rightleftarrows}} \textit{system transfer function.}$$

On this level of generality, the word *system* might be deleted without loss of clarity.

On a more specific level, *system* might be replaced by a term designating the particular system (or component), such as *optical, screen-film, scanner, gamma-ray camera* (or *detector, recorder, processor, display*), etc.

Thus for example, the FT of the *detector (point* or *line) spread function,* which has been called the "modulation transfer funciton" of the generalized† detector (*14,15*) in nuclear medicine, would be called the *detector transfer function.* Although this function could in general be complex, its values would be real for the usual symmetric *detector spread function.* In particular, the *detector transfer function* (like the *optical transfer function*) might assume negative values, indicating "spurious resolution" (*13,14*).

In addition, to preserve the degree of generality that is most convenient for asymmetric *spread functions,* the absolute value and the argument of all *system transfer functions* might be designated *modulation transfer function* and *phase transfer function,* respectively, in nuclear medicine as currently in optics and radiology.

* Modified by *point* or *line* when ambiguity would otherwise result.

† The term generalized *detector spread function* refers to the shape of the normalized expected count-density profile due to a point (or line) source of radioactivity at a certain depth within a tissue-equivalent scattering medium. Thus it is dependent on the geometrical response of the collimator, septal penetration, scattering in the medium and collimator, the energy resolution of the detector, and "window" setting of the pulse-height analyzer.

Finally, it appears to be generally agreed that the use of three letter symbols, such as OTF and MTF, to designate these terms is cumbersome and should be replaced by a single-letter notation without subscripts whenever possible.

In the interest of finding an acceptable set of terms and symbols to designate these concepts, your comments, criticisms, and alternative suggestions would be greatly appreciated.

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DOSIMETRY OF ^{87m}Sr

Calculating the radiation dose from ^{87m}Sr using the formulas from Johns and Cunningham (*1*), we found a bone dose of 14.8 mrad/100 μCi. This value agrees rather satisfactorily with those calculated by others (*2–5*) which are in the range 10.0–14.0 mrad/100 μCi. However, the value of 40.3 mrad