Proposed List of Terms and Definitions

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Our goal is to develop a list of agreed-upon terms and definitions to facilitate clear communication in IPASC discussions, as well as for inclusion in future IPASC consensus publications and/or formalized standards developed through Standards Developing Organizations (IEC, ISO, AAPM, etc.). Term definitions may be modified based on final IPASC phantom design and performance test method recommendations. Please note that some of these definitions would be more critical for an official standard from a standards developing organization (ISO/IEC, AAPM, etc.), but need not be included in an initial consensus document. Note that definition of image quality metric terminology here does not imply that those metrics must be adopted as part of proposed phantom-based image quality test methods.

Informational References (not necessarily Normative References):

ANSI Z136.1:2014: American National Standard for Safe Use of Lasers
IEC 60825-1:2014: Safety of laser products – Part 1: Equipment classification and requirements
IEC 61391-1:2006: Ultrasonics – Pulse-echo scanners – Part 1: Techniques for calibrating spatial measurement systems and measurement of system point-spread function response
IEC 61391-2:2006: Ultrasonics – Pulse-echo scanners – Part 2: Measurement of maximum depth of penetration and local dynamic range
ISO 80000-7:2008: Quantities and units – part 7: Light
ISO 62127-1:2007+AMD1:2013: Ultrasonics - Hydrophones - Part 1: Measurement and characterization of medical ultrasonic fields up to 40 MHz
IEC 61828:2001: Ultrasonics – Focusing transducers – Definitions and measurement methods for the transmitted fields
ISO 60854:1986: Methods of measuring the performance of ultrasonic pulse-echo diagnostic equipment, IEC/TR 60854, 1986
CLSI EP17-A2:2012: Evaluation of Detection Capability for Clinical Laboratory Measurement Procedures; Approved Guideline—Second Edition
Sliney D. H., "Radiometric Quantities and Units Used in Photobiology and Photochemistry: Recommendations of the Commission Internationale de l'Eclairage (International Commission on Illumination)", Photochem Photobiol 83:425-432, 2007.
Pogue et al., "Contrast-detail analysis for detection and characterization with near-infrared diffuse tomography"
Barrett and Myers, Foundations of Image Science, 1st Ed. Hoboken, New Jersey, 2004
McCollough, C.H., et al. The phantom portion of the American College of Radiology (ACR) computed tomography (CT) accreditation program: practical tips, artifact examples, and pitfalls to avoid. Medical physics 31, 2423-2442 (2004).
Braslavsky, S. E., "Glossary of Terms Used in Photochemistry", Pure Appl. Chem 79(3), 2007
Kessler, L. G. et al., "The emerging science of quantitative imaging biomarkers terminology and definitions for scientific studies and regulatory submissions", Stat Methods Med Res 24(1), 2015

1. Radiometry and laser safety
    a. **Pulse duration**: the duration of an optical pulse, usually measured as the time interval between the half-power points on the leading and trailing edges of the pulse. (ANSI Z136.1)
    b. **Pulse repetition rate**: the number of pulses occurring per second, expressed in Hertz. (ANSI Z136.1)
    c. **Spectral bandwidth or spectral linewidth**: full width at half maximum of optical pulse energy spectrum, which may vary as a function of wavelength depending on the light source.
    d. **Fluence or radiant fluence**: quotient of the radiant energy of all radiation incident on the outer surface of an infinitely small sphere centered at the given point by the areas of the diametrical cross-section of that sphere, with units of millijoules-per-centimeter-squared (mJ/cm^2). (based on ISO 80000-7, Braslavsky 2007, and Sliney 2007)
        i. Note: fluence within turbid media will often exceed the incident radiant exposure due to multiple scattering, especially for large-area beams.
    e. **Irradiance**: radiant power incident upon a surface per unit area, expressed in watts-per-centimeter-squared (W/cm^2). (ANSI Z136.1)
    f. **Radiant Exposure**: radiant energy incident upon a surface per unit area, expressed in units of milliJoules-per-centimeter squared (mJ/cm^2) (based on Z136.1 and Sliney, Phys Med Biol 83, 2007).
        i. Note: IPASC intends to use the term radiant exposure to describe incident optical energy per area. This is the most precise terminology and is consistent with standardized definitions set by ISO, IEC, ANSI, and IUPAC. The term “incident fluence” is commonly used by the community to describe radiant exposure, but this usage can lead to ambiguity or conceptual errors (e.g., incorrectly interchanging incident fluence with subsurface fluence). The term “fluence” without the modifier “incident” should never be used to describe radiant exposure.
    g. **Maximum permissible exposure (MPE)**: the level of laser radiation to which an unprotected person may be exposed without adverse biological changes in the eye or skin. (ANSI Z136.1:2014)
        i. Note 1: MPEs are defined in terms of irradiance or radiant exposure, not fluence or fluence rate. The use of the term ‘fluence’ to describe optical energy per unit area of exposed tissue surface is incorrect, especially in the context of a Z136.1 analysis. Fluence and radiant exposure are fundamentally different quantities, and fluence at the tissue surface will include backscattered light from the tissue. The word “fluence” does not appear once in the Z136.1 standard. (see Sliney 2007, Braslavsky 2006, ANSI Z136.1:2014)

    ii. Note 2: the often-quoted value of an ANSI safety limit of 20 mJ/cm^2 is not always the correct MPE value for a given exposure scenario. This number only applies to single-pulse exposure (no pulse train) of skin at wavelengths of 400-700 nm. A future consensus document should elaborate on general considerations for Z136 analyses of PAI devices. For instance, the single-pulse MPE at 700 nm is 20 mJ/cm^2, but following the methods in ANSI Z136.1:2014, the MPE per pulse for repetitive pulsing at 20 Hz for >10 seconds is actually half this limit. MPEs are also wavelength-dependent, increasing (i.e. less restrictive) with increasing wavelength from 700-1400 nm.

2. Transducer parameters
    a. Coordinate system nomenclature
        i. **Axial direction**: the normal axis from the face of an ultrasound transducer element or array, corresponding to acoustic propagation axis and, usually, the vertical direction or depth in 2D images.
        ii. **Lateral direction**: the horizontal direction in the image plane. For 1D ultrasound transducer arrays, the axis along the array length and tangential to the surface of the transducer.
        iii. **Elevational direction**: the normal of the image plane for an ultrasound transducer that produces 2D images.
    b. **Fractional bandwidth**: width of transducer acoustic frequency spectrum divided by the center frequency, expressed as a percentage. Imaging system bandwidth is dependent on the characteristics of both transducer and system electronics. Bandwidth should be specified as either one-way (receive only) or two-way (transmit and receive).
    c. **Center frequency**: frequency corresponding to the midpoint between the cutoff frequencies defining the transducer bandwidth .
    d. **Transducer element**: a specific material element capable of converting electrical energy to mechanical energy and reciprocally converting mechanical energy to electrical energy. (IEC TR 60854 1986)
    e. **Pitch**: spacing between adjacent transducer array elements, in units of millimeters.
    f. **Transducer sensitivity**: electrical signal amplitude generated by an ultrasound transducer in response to an acoustic pressure pulse, expressed in millivolts per Pascal (mV/Pa). Varies with ultrasonic frequency.
    g. **Noise equivalent pressure**: acoustic pressure within a specified bandwidth that generates peak electrical signal amplitude equal to the root-mean-square level of electrical noise generated by the ultrasound transducer (typically connected with analog electrical amplifier) in the absence of external stimulus by ultrasonic pressure waves. Expressed in Pascals (Pa).
3. Tissue properties
    a. **Ideal tissue-mimicking material**: material in which light absorption, light scattering, light reflection, light refraction, sound propagation velocity, acoustic

reflection, acoustic scattering, and acoustic attenuation properties are similar to those of a declared tissue type over specified optical wavelength range and acoustic frequency range.

b. **Optical absorption coefficient (** μ_a **)**: parameter characterizing the exponential attenuation of ballistic light due to absorption per unit thickness of material, units of inverse centimeters (cm^{-1}). (Welch)
c. **Optical scattering coefficient (** μ_s **)**: parameter characterizing the exponential attenuation of ballistic light due to scattering per unit thickness of material, units of inverse centimeters (cm^{-1}). (Welch)
d. **Optical scattering anisotropy factor (** g **)**: A measure of the degree of anisotropy in scattering, computed as the expected (average) value of the cosine of the scattering angle. (Welch p. 49)
e. **Optical reduced scattering coefficient (** μ_s' **)**: the product of scattering coefficient and the quantity one minus the anisotropy factor. Represents a medium with equivalent scattering attenuation but an isotropic scattering phase function. (Welch)
f. **Optical effective attenuation coefficient (** $\mu_{eff} = \sqrt{3\mu_a(\mu_a + \mu_s')}$ **)**: A measure of effective attenuation due to combined absorption and scattering under the diffusion approximation of light transport in a turbid medium. (Welch)
g. **Group refractive index (** n **)**: the ratio of the speed of light in a vacuum to the speed of light in a given medium.
h. **Speed of sound**: group velocity of sound waves propagating in a medium.
i. **Acoustic attenuation coefficient**: loss in acoustic signal amplitude during propagation through a medium due to the combination of acoustic absorption and scattering, divided by the pathlength traveled, in units of dB/cm. Varies significantly with acoustic frequency.
j. **Acoustic backscatter coefficient**: mean acoustic power scattered in the 180 degree direction by a specified object with respect to the direction of the incident beam, per unit solid angle per unit volume, divided by the incident beam intensity. For a volume filled with many scatterers, the scatterers are considered to be randomly distributed. The mean power is obtained from different spatial realisations of the scattering volume. (IEC 61391-1)
k. **Acoustic impedance**: product of medium density and speed of sound.

4. Image quality metrics
    a. **Axial resolution**: Full width at half-maximum (FWHM) along the axial direction of a point spread function resulting from imaging a sub-resolution target (e.g. spherical beads or cylindrical filaments).
    b. **Lateral resolution**: Full width at half-maximum (FWHM) along the lateral direction of a point spread function resulting from imaging a sub-resolution target (e.g. spherical beads or cylindrical filaments).

c. **Elevational resolution**: Full width at half-maximum (FWHM) along the elevational direction of a point spread function resulting from imaging a sub-resolution target (e.g. spherical beads or cylindrical filaments).
d. **Point target**: absorber whose scattering surface dimensions are so small that it cannot be distinguished (except by signal amplitude) by the imaging system from a similar target whose scattering surface is an order of magnitude smaller. The backscatter cross section of a standard point target should be a simple function of frequency over the range of frequencies studied. (adapted from IEC 61391-1).
e. **Line target**: line target cylindrical optical absorber whose diameter is so small that the absorber cannot be distinguished by the imaging system from a cylindrical absorber with diameter an order of magnitude smaller, except by signal amplitude. (adapted from IEC 61391-1)
f. **Point spread function**: characteristic response in three dimensions of an imaging system to a high-contrast point target. (IEC 61391-1)
g. **Line spread function**: characteristic response in three dimensions of an imaging system to a high-contrast line target. (IEC 61391-1)
h. **Ultrasound field of view**: 2D area or 3D volume which is insonated by the ultrasound beam during the acquisition of echo data to produce one image frame. (IEC 61391-1).
i. **Photoacoustic field of view**: 2D area or 3D volume which is optically illuminated and acoustically detected to produce one image frame.
j. **Spatial measurement accuracy**: ability of a device to enable measurements of distances between target image features such as layer thickness, vessel diameter, vessel cross-sectional area, or tumor volume.
k. **Image amplitude uniformity**: measure of spatial variation in image amplitude within the field of view.
l. **Global dynamic range**: 20 $\log_{10}$ of the ratio of the maximum to the minimum signal amplitude, even with changes of settings, that a scanner can process without distortion of the output signal, in dB. (IEC 61391-2)
m. **Local dynamic range**: 20 $\log_{10}$ of the ratio of the minimum signal amplitude that yields the maximum grey level in the digitized image to the maximum signal amplitude that yields the lowest grey level at the same location in the image and the same settings, in dB (adapted from IEC 61391-2)
n. **Displayed dynamic range**: 20 $\log_{10}$ of the ratio of the amplitude of the maximum signal that does not saturate the display to the minimum signal that can be distinguished in the display under the scanner test settings, in dB. (adapted from IEC 61391-2)
o. **Limit of Blank (LoB):** a threshold above which measurements from the quantity with true state of measurand = 0 are obtained with probability α (probability of falsely claiming that the true state of measurand > 0).
p. **Limit of detection (LoD):** the measured quantity value, obtained by a given measurement procedure, for which the probability of falsely claiming that the true

state of measurand = 0 is β, given a probability α of falsely claiming that the true state of measurand > 0. Generally, IUPAC recommends $\alpha = \beta = 0.05$.

q. **Limits of quantitation (LoQ)**: the lowest and highest values of a measurand that can be reliably detected and quantitatively determined with stated acceptable precision and bias, under specified experimental conditions.
r. **Signal-to-noise ratio (SNR)**: ratio of the image amplitude of a target inclusion averaged over a region of interest to the standard deviation of a local background region.
s. **Contrast ratio**: ratio of the image amplitude of a target inclusion averaged over a region of interest to the amplitude of a local background region averaged over an equal-sized region of interest.
t. **Contrast-to-noise ratio or "Lesion SNR":** The ratio of the difference in mean target inclusion and background amplitude averaged over regions of interest divided by the square root of the sum of squares of inclusion and background amplitude standard deviations. $(A_{target} - A_{back})/\sqrt{\sigma^2_{target} + \sigma^2_{back}}$ Typically used in ideal observer modeling analysis (Smith et al. IEEE Trans Sonics Ultrason 30, 1983, Barrett and Myers, Foundations of Image Science, 1st Ed. 2004).
u. **Maximum Depth of Visualization**: maximum distance in a tissue-mimicking phantom of specified properties for which the ratio of the digitized B-mode image data from background absorbers to the digitized B-mode image data displaying only electronic noise equals 1.4. (adapted from IEC 61391-2)
v. **Low-contrast object detectability**: ability of a device to visualize absorptive targets in the tissue (e.g. blood vessels). Assessed via contrast-detail analysis of targets with varying size, depth, and absorption coefficient. Contrast to noise ratio of targets shall be measured, with minimum detectability defined as a threshold of 2 (~6 dB).
w. **Contrast-detail analysis**: Evaluation of minimum target inclusion detectability as a function of contrast (absorption coefficient) and size. (Pogue, Med Phys 2000)
x. **Minimum detectable optical absorption coefficient**: minimum absorption coefficient for which a target of diameter smaller than the spatial resolution may be detected. Varies with target depth in an attenuating medium, target size, and illumination wavelength due to spectral variations in tissue attenuation.
    i. Note: Defining detectability limits based on absorption coefficient is more generalizable across systems and applications, as it is independent of chromophore concentration or molar extinction coefficient.