Common Formulae used in Neutron Radiography

The following formulas are generally approximations commonly used in neutron radiography.

Geometric Unsharpness (same units as *t*)

Geometric Unshaprness is the loss of definition that is the result of geometric factors of the radiographic setup. A result of not having a point source or perfectly collimated beam of neutrons and the distance separating the object from the image plane.

$$U_g = \frac{t}{L/D}$$

$$*U_g = \frac{D \times t}{L - t}$$

Where U_g is the geometric unsharpness,
t is the object thickness (more accurately the distance from image plane to the part location of interest),
L is the distance from the aperture to the image plane,
and D is the diameter of the aperture.

use this when *L* not substantially larger than *t (a more accurate equation).

Image Plane Flux (n/cm²/s)

Flux is the number of neutrons passing through a centimeter squared per second, The flux at the image plane will determine what the exposure time will be and is a function of the flux at the source, and distance from the source and the diameter of the aperture.

$$\varphi_i = \frac{\varphi_s}{16(L/D)^2}$$

Where φ_s is the source flux,
φ_i is the image plane flux,
L is the distance from the aperture to the image plane,
and D is the diameter of the aperture.

Fluence (n/cm²)

Fluence is the number of neutrons passing through a centimeter squared. A certain fluence will be required to produce an image. The fluence required is dependent on the image capture method and conversion material.

$$\Phi = \varphi T$$

Where Φ is fluence,
φ is flux
and T is time.

Exposure time (s)

$$EXP = \frac{\Phi}{\varphi}$$

Where Φ is the fluence required to expose film to proper density (1×10^9 for optical density of 2.5 using Agfa D-3 S.C.)
and φ is the flux at the image plane.

Film Density/Transmission

Film density is a logarithmic measure of the light transmitted through a film.

$$I_T = \frac{1}{10^D}$$

$$D = -\log_{10}(I_T)$$

Where I_T is the transmitted light intensity (% in decimal)
and D is the film density (no units).

Collimator

Trigonometry allows us to determine the maximum beam divergence angle in each direction based on the collimator and aperture dimensions. The divergence angle will gradually increase with increasing distance from the center of the beam line. The DAI device allows direct measurement of the divergence angle.

$$Tan\theta = 0.5\frac{(W - D)}{L_b}$$

$$Tan\theta = 0.5\frac{(F - D)}{L}$$

Where θ is the beam divergence angle,
W is the beam tube diameter,
F is the film dimension (diagonal) or beam diameter,
L_b is the length of the beam tube,
L is the distance from the source to the image plane,
and D is the diameter of the aperture.

Exposure time correction

Correction of exposure time to achieve a target density can easily and accurately be performed over a wide range of densities by rearranging this equation.

$$T_2 = T_1 \frac{D_2}{D_1}$$

Where T_2 is the new exposure time,
T_1 is the original exposure time,
D_1 is original film density,
and D_2 is the desired film density.

Beam Attenuation

Neutron attenuation is related to the macroscopic cross section for the material for a specific energy of neutrons and the amount of material the neutrons pass through. This ignores buildup (multiple scatters) and buildup (a result of the energy distribution of neutrons).

$$I_o = I_i\, e^{-(\mu t)} \qquad t = \frac{-\ln\left(\frac{I_o}{I_i}\right)}{\mu}$$

Where I_i is the beam intensity on the inbound side
I_o is the beam intensity on the outbound side,
μ is the material's linear attenuation coefficient or macroscopic cross section,
and t is the material's thickness (cm).

Inverse Square Rule (approximation)

A gross approximation useful with radiation safety. If you double the distance you are from a point source of radiation, then doses should decrease by a factor 4, ignoring shielding, and scattering.

$$I_2 = I_1 \frac{d_1^{\,2}}{d_2^{\,2}}$$

Where I_1 is the beam intensity at location d_1,
and I_2 *is the beam intensity at location* d_2.

NU Calculation

The NU device is used to indirectly measure the L/D of an imaging system. The appropriate rod is selected based on the image then the known distance to that rod and the diameter of the wire form a similar triangle with the diameter of the aperture and the distance to it.

$$\frac{L}{D} = \frac{b}{d}$$

Where L is the distance from the source to the image plane,
D is the diameter of the aperture,
b is the distance of the NU rod from the film,
and d is the diameter of the NU rod.