

Summary of Protocol for Calibrating a Neutron Beam

by

Arlene J. Lennox, PhD
Fermi National Accelerator Laboratory
P. O. 500 Batavia, Illinois 60510 USA

At present neutron calibration is done with respect to a standard photon beam because there is no well-established standard neutron beam. An ionization chamber which is equally sensitive to photons and neutrons is calibrated by standards group, which provides a value for the chamber calibration factor, N_x , in Roentgen/Coulomb at absolute temperature, T_c , and pressure, P_c , in millibar. (In the United States this is done by the National Bureau of Standards or one of its designated calibration centers). The standard chamber is then used to measure the strength of a cobalt or cesium source at the local institution. Once its strength has been determined, the local source is used to find N_x for the chamber used for daily calibration. This is done using the relationship:

$$N_x = \frac{\dot{X}_0 \cdot F}{\frac{DV}{Dt} \cdot \text{TPCor} \cdot C}, \quad (1)$$

where \dot{X}_0 is the source strength in Roentgen/sec at some initial time, t_0 ; F is the decay factor to correct for the number of days elapsed since the original strength measurement and TPCor is the temperature-pressure correction factor:

$$\text{TPCor} = \frac{T \cdot P_c}{T_c \cdot P}. \quad (2)$$

T and P are the temperature and pressure at which the local calibration is being made. The charge collected in the ionization chamber in time, Dt , is the product of the capacitance, C , of the integrating circuit and the observed voltage change, DV . Chambers used for neutron calibrations are usually made of tissue equivalent (TE) material.

For calibrating the neutron beam the ionization chamber is placed at sufficient depth in a phantom so that electronic equilibrium is achieved when the phantom and chamber are exposed to the neutron beam. (At Fermilab the chamber is placed in 10 cm of tissue equivalent liquid - other facilities use 5 cm of water). From Bragg-Gray theory, if Q_T is the total ionization charge measured in the neutron beam then the total dose to muscle tissue, D_T , is:

$$D_T = N_X \cdot A_w \cdot f_{med} \cdot d \cdot \frac{(S_{w,g})_N}{(S_{w,g})_C} \cdot \frac{\bar{w}_N}{w_e} \cdot \frac{K_N}{K_C} \cdot Q_T \cdot \text{TPCor} \quad (3)$$

where A_w is the attenuation and scattering factor for photons in a tissue-equivalent chamber of equilibrium wall thickness;

f_{med} is the muscle tissue dose-to-exposure conversion factor for photons;

d is the chamber displacement factor for dose measurements in the TE liquid phantom in the neutron beam;

$(S_{w,g})_N$ is the ionization chamber gas-to-wall conversion factor for the secondary charged particles created in the neutron beam;

$(S_{w,g})_C$ is the ionization chamber gas-to-wall conversion factor for the secondary charged particle created in the photon beam;

K_C is the quotient of mass energy absorption coefficients for muscle tissue to A-150 tissue equivalent plastic for photons;

K_N is the neutron kerma factor ratio for muscle tissue relative to A-150 tissue equivalent plastic.

In practice, if C is the capacitance of the integrator connected to the ionization chamber then $Q_T = CDV$ and

$$D_T = \text{constant} \cdot N_X \cdot C \cdot DV \cdot \text{TPCor(IC)} \quad (4)$$

where TPCor(IC) designates the correction for the temperature and pressure at the location of the ionization chamber. (For the Fermilab beam, using tissue equivalent liquid as the calibration phantom this constant equals 0.009364 Gray/Roentgen. Values used to calculate this constant for other neutron beams can be found in

AAPM Report No.7, Protocol for Neutron Beam Dosimetry, published by the American Institute of Physics, 1980. Some updated values are given in "Uniformity in dosimetry protocols for therapeutic applications of fast neutron beams," *Medical Physics*. 14(6), Nov/Dec 1987.)

Of course the ionization chamber cannot be in the beam during treatment, so there must be another way to monitor the beam during therapy. A parallel plate transmission chamber is permanently installed just downstream of the neutron production target. When the ionization chamber in its calibration position receives a dose of 1 Gray as determined by equation (4), the temperature-pressure corrected reading in the transmission chamber equals one monitor unit. The conversion factor, K, relating absorbed dose at the calibration position to the signal, DV_{TC} , in the transmission chamber is:

$$K = \frac{D_t}{CDV_{TC} \cdot TPCor(TC)} \quad (5)$$

At the calibration position with $D_t = 1$ Gray:

$$K \cdot C \cdot DV_{TC} \cdot TPCor(TC) = 1 \text{ monitor unit} = 1 \text{ M.U.} = 1 \text{ Gray}$$

At other positions, 1 M.U. does not equal 1 Gray, but:

$$D_t(\text{Gray}) = \text{M.U.} \cdot \text{TSR}$$

where the tissue-standard-ratio, TSR, is defined by:

$$\text{TSR} = \frac{\text{dose at any depth}}{\text{dose at calibration depth}}$$

The TSR is similar to the %-depth dose used in photon calibration except that %-depth dose is referred to the depth of maximum dose, D_{max} , while the TSR is referenced to the dose at calibration, which is usually 5 or 10 cm.

APPENDIX

Derivation of Equation (3)

If a chamber is exposed to a neutron beam in air the dose to the gas is:

$$D_{g,N} = Q_N \cdot \frac{W_N}{e} \cdot \frac{1}{M_g} \quad (6)$$

Similarly, if the same TE chamber is exposed to a photon beam from cobalt or cesium the dose to the chamber gas due to the photons is:

$$D_{g,C} = Q_C \cdot \frac{W_C}{e} \cdot \frac{1}{M_g} \quad (7)$$

where the subscripts N and C refer to neutron and photon beams, respectively. Q is the ionization charge, W/e is the average energy required to produce an ion pair in the gas cavity, and e is the charge on an electron. The dose to the wall is then

$$D_{w,g} = (S_{w,g})_C \cdot D_{g,C} \quad (8)$$

where $(S_{w,g})_C$ is the gas-to-wall dose conversion factor, also called the effective mass stopping power ratio. The dose to tissue, D_t , is related to the wall dose by

$$D_{t,C} = K_C \cdot D_{w,g} \quad (9)$$

For photons
$$K_C = \frac{(m_{en}/r)_t}{(m_{en}/r)_w} \quad (10)$$

where the m_{en}/r are the mass energy absorption coefficients for photons.

Johns and Cunningham (1969) have suggested a way to relate the dose to the wall to exposure, X :

$$D_{w,C} = f_w \cdot X \cdot A_w \quad (11)$$

where f_w is the exposure-to-dose conversion factor and A_w is a correction factor for photon attenuation and scattering in the chamber wall and buildup cap. If a tissue equivalent chamber is used then the w subscripts in (11) may be replaced by t for tissue and (11) becomes:

$$D_{t,C} = f_{med} \cdot X \cdot A_w, \quad (12)$$

where it is assumed that the attenuation factor, A , is the same for tissue and the wall. Equating (9) and (11):

$$f_{med} \cdot X \cdot A_w = K_C \cdot D_{w,C}$$

and from (8)

$$= K_C \cdot (S_{w,g})_C \cdot D_{g,C}$$

and using (7)

$$f_{med} \cdot X \cdot A_w = K_C \cdot (S_{w,g})_C \cdot Q_C \cdot \frac{W_C}{e} \cdot \frac{1}{M_g} \quad (13)$$

Recall that the basic definition of the chamber calibration factor is:

$$N_X = \frac{X}{Q_C}.$$

Applying this relationship to (13) yields:

$$f_{med} \cdot N_X \cdot Q_C \cdot A_w = K_C \cdot (S_{w,g})_C \cdot Q_C \cdot \frac{W_C}{e} \cdot \frac{1}{M_g}$$

from which:

$$M_g = \frac{1}{N_C \cdot f_{med} \cdot A_w} \cdot \frac{W_C}{e} \cdot (S_{w,g})_C \cdot K_C \quad (14)$$

Just as equations (8) and (9) follow from (7) one can begin with equation (6) for neutrons and write the following:

$$D_{w,g} = (S_{w,g})_N \cdot D_{g,N} \quad (15)$$

and

$$D_t = K_N \cdot D_{w,g} \cdot d, \quad (16)$$

where K_N is the neutron kerma factor ratio for muscle relative to A-150 TE plastic and d is a chamber displacement correction factor. Combining (14), (15) and (16) we get:

$$D_t = K_N \cdot (S_{w,g})_N \cdot Q_N \cdot \frac{w_N}{e} \cdot d \cdot \frac{1}{M_g} \quad (17)$$

Substituting (14) into (17) :

$$D_t = N_C \cdot A_w \cdot f_{med} \cdot \frac{(S_{w,g})_N}{(S_{w,g})_C} \cdot \frac{w_N}{w_C} \cdot \frac{K_N}{K_C} \cdot Q_N \quad (18)$$

For a mixed photon and neutron beam Q_N is replaced by the total charge, $Q_T = Q_C + Q_N$, since the chamber is assumed to be equally sensitive to photons and neutrons.