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THE USE OF THE ROENTGEN EQUIVALENT PHYSICAL (REP)

Karl Z. Morgan

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THE USE OF THE ROENTGEN EQUIVALENT PHYSICAL (REP)

Karl Z. Morgan

During the past few years, since the use of ionizing radiations other than X and gamma radiations has become commonplace, and since ultra high voltage X-ray equipment has been developed, there has been an increasing need for a tissue dose unit which would be more or less physically equivalent to the roentgen. The definition of the roentgen is such that it applies only to X and gamma radiation and, in practice, dosage can be measured directly in roentgens only at relatively low quantum energies. Further, the roentgen is a unit of dosage to air and it is frequently difficult to relate it to dosage to biological tissue or other media.

In 1944, H. M. Parker suggested as a unit of measurement of tissue dose the rep which he defined as the dose corresponding to the absorption, from ionizing radiation, of 83 ergs per gram of tissue (see note at bottom of page 6). At a meeting of representatives of the U. S. Radiation Protection Committee and of the Radiological Society of North America, Inc. in San Francisco in December, 1948, it was decided to increase the magnitude of the tissue dose unit. The majority of those who considered this problem favored the use of 93 ergs/gm, but others (including the writer) preferred the use of 95 or 100 ergs/gm. The name of this unit was not specified at the San Francisco meeting, but several writers* have since chosen to call it the rep and so this name is used in this discussion. A number of other units of ionizing radiation dose have been suggested by both Americans and British, but it is not the intent of this paper to discuss them.

The purpose of this paper is to point out the fact that to convert esu/cc of air, as measured in an air cavity chamber, to reps requires a knowledge of stopping power and of the number of electron volts per ion pair characteristic of the ionizing particles. It is indicated that in the case of beta, electron

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* See paper by H. M. Parker, "Tentative Dose Units for Mixed Radiations," Radiology, 54, 2, Feb. 1950.

and gamma radiations the rep is equal approximately to one esu per cc of air in a small tissue cavity if the rep is defined as the dose of ionizing radiation that delivers 95 ergs per gram of tissue.

The Bragg-Gray principle states,

$$\left(\frac{dE}{dv}\right)_a = \frac{1}{B_t}\left(\frac{dE}{dv}\right)_t \qquad (1)$$

in which

$\left(\frac{dE}{dv}\right)_a$ = energy loss per unit volume in air cavity of chamber

B_t = volume stopping power of the medium relative to air

$\left(\frac{dE}{dv}\right)_t$ = energy loss per unit volume in tissue medium

If we define the rep as that dose of ionizing radiation resulting in the absorption of 95 ergs per gram of tissue,

$$\frac{\text{rep}}{\text{hr}} = \frac{\text{esu}}{(\text{cc})_a\ \text{hr}} \times \frac{1}{4.8 \times 10^{-10}} \times \frac{32.5\ N}{1} \times \frac{1.602 \times 10^{-12}}{1} \times B_t \times \frac{1}{\rho_t} \times \frac{1}{95}$$

in which,

$\frac{\text{esu}}{(\text{cc})_a\ \text{hr}}$ = the number of esu per cc of air per hour as determined experimentally,

$\frac{\text{rep}}{\text{hr}}$ = the corresponding number of reps of tissue dose,

4.8×10^{-10} = the number of esu per ion pair,

$N \times 32.5$ = the average number of electron volts per ion pair produced by the ionizing particle under consideration. N is equal to unity for the electrons from gamma radiation and for betas, and to about 36/32.5 for alpha particles,

1.602×10^{-12} = the number of ergs per electron volt,

ρ_t = the density of tissue medium measured in gm/cm^3.

Therefore,

$$\frac{\text{rep}}{\text{hr}} = 1.14 \times 10^{-3} \times \left(\frac{\text{esu}}{(\text{cc})_a \text{ hr}}\right) \times \frac{N\ B_t}{\rho_t} \qquad (2)$$

or,

$$\frac{\text{rep}}{\text{hr}} = 1.14 \times 10^{-3} \times \left(\frac{\text{esu}}{(\text{cc})_a \text{ hr}}\right) \frac{N\ P_t}{\rho_a} = 0.884 \times \left(\frac{\text{esu}}{(\text{cc})_a \text{ hr}}\right) N\ P_t \qquad (3)$$

in which P_t is the mass stopping power of the ionizing particles in tissue, relative to air.

P_t is related to B_t by the equation $\quad B_t = P_t \dfrac{\rho_t}{\rho_a} \qquad (4)$

and the general expression for P_t is

$$P_t = \frac{\Sigma(Z/A)_t \ (S_e)_t}{\Sigma(Z/A)_a \ (S_e)_a} \qquad (5)$$

in which $(Z/A)_t$ and $(Z/A)_a$ are the ratios of the atomic number to the atomic weight of the tissue medium and air respectively. They are the electron densities in the two media. The terms $(S_e)_t$ and $(S_e)_a$ are the stopping powers per electron in the tissue medium and air respectively.

In the case of beta radiation, gamma radiation, or electrons, equation (3) becomes,

$$\frac{\text{rep}}{(\text{hr})_{\beta, e^-}} = 0.884 \times \left(\frac{\text{esu}}{(\text{cc})_a \text{ hr}}\right) P_t \doteq \frac{\text{esu}}{(\text{cc})_a \text{ hr}} \qquad (6)$$

since P_t = 1.14 for 0.1 Mev beta or electrons and

1.13 for 2 Mev betas or electrons or $0.884\ P_t \doteq 1.$

In fact the reason for choosing to define the rep in terms of 95 ergs/gm of tissue is that it satisfies equation (6) which many research workers have found convenient to use. *

In the case of alpha radiation, equation (3) becomes

$$\frac{\text{rep}}{(\text{hr})_\alpha} = 0.98 \times \left(\frac{\text{esu}}{(\text{cc})_a \text{ hr}}\right) P_t \doteq 1.17 \times \left(\frac{\text{esu}}{(\text{cc})_a \text{ hr}}\right) \qquad (7)$$

since P_t = 1.2 for 4 Mev alpha, and
1.22 for 2 Mev alpha

The measurements made with an extrapolation chamber furnish a good example for the application of the above equation when converting the esu/cc of air in a tissue cavity to reps. In this case the esu/cc of air per hour in the air cavity between the collection plates of the chamber (plates made of tissue equivalent material) is determined from the equation,

$$\frac{\text{esu}}{(\text{cc})_a \text{ hr}} = 3600 \times V \times \frac{3 \times 10^9}{Rv} \times \frac{760}{p} \times \frac{T}{273} = 3.01 \times 10^{13} \frac{TV}{pRv} \qquad (8)$$

---

* One $\frac{\text{esu}}{(\text{cc})_a} = \frac{1.602 \times 10^{-12} \times 32.5}{4.8 \times 10^{-10} \times 0.001293} = 83.9 \frac{\text{ergs}}{(\text{gm})_a}$

According to the Bragg-Gray principle, if one $\frac{\text{esu}}{(\text{cc})_a}$ is lost in a microscopically small air cavity in the tissue medium, the $\frac{\text{erg}}{(\text{gm})_t} = 83.9\ P_t \doteq 95$ in the case of electrons, β^- rays and gamma radiation.

in which

V = electrometer potential in volts required to maintain the galvanometer current at zero

R = resistance in ohms

v = collecting volume of air cavity in cc

T = absolute temperature

p = pressure in mm of Hg

3×10^9 = the number of esu of current per ampere

3600 = the number of seconds per hour.

It follows then, that

$$\left(\frac{\text{rep}}{\text{hr}}\right)_{\beta^-} = 3 \times 10^{13} \times \frac{TV}{pRv} \qquad (9)$$

and that

$$\left(\frac{\text{rep}}{\text{hr}}\right)_{\alpha} = 3.52 \times 10^{13} \times \frac{TV}{pRv} \qquad (10)$$

If one chooses to define the rep in terms of 93 ergs/gm of tissue as recommended by some persons, the numerical factors in equations (9) and (10) must be increased by 2 percent. The number 93 comes from the relative electron density in water and air as follows:

$$\frac{\Sigma(Z/A)_{\text{water}}}{\Sigma(Z/A)_{\text{air}}} = 1.11, \text{ and } 1.11 \times 83.9 = 93 \text{ ergs/gm} \qquad (11)$$

The writer objects to the choice of 93, because it applies approximately to X radiation only in the Compton region. Perhaps a unit based on the dose corresponding to an energy absorption in tissue (and define the tissue components) of 95 or 100 ergs/gm of tissue would be the best choice for an interim unit until it can be discarded in favor of measurement of ergs per gram of tissue. When we can get away from a desire to relate the dose of ionizing radiation to the outmoded roentgen unit there will be advantages in expressing the dose to any particular medium in terms of the ergs delivered per gram of medium.