nm/ CONCISE COMMUNICATION

SPECIFIC GAMMA-RAY AND EQUILIBRIUM ABSORBED-DOSE CONSTANTS FOR BARIUM-135m

Ibrahim B. Syed and Fazle Hosain

The Johns Hopkins Medical Institutions, Baltimore, Maryland

An examination of currently used radionuclides in bone scanning (*1*) would indicate the need for a better agent. Recent production and evaluations of ^{135m}Ba in animals (*2–4*) and humans (*5*) strongly suggest it to be a potential radionuclide for bone scanning among the alkaline earth metals. Its half-life of 28.7 hr and photon energy of 268 keV are most desirable for skeletal imaging. We therefore intend to present aspects of calibration and dosimetry of ^{135m}Ba before its widespread use. We also feel that there is a need for publication of specific gamma-ray constants (Γ) of important radionuclides in MIRD pamphlets.

Barium-135m decays to stable ^{135}Ba by 100% isomeric transition from an energy level of 0.268 MeV with a half-life of 28.7 hr. The 268-keV photons of ^{135m}Ba are 85% internally converted ($\alpha_K = 3.8$, $\alpha_L = 1.42$, and $\alpha_M = 0.47$).

SPECIFIC GAMMA-RAY CONSTANT AND CALIBRATION

The value of Γ, the specific gamma-ray constant, must be known to calibrate the activity of ^{135m}Ba using either a standard (Type 1383A) beta-gamma ionization chamber of General Radiological Ltd., a Mediac isotope calibrator, or any allied instrument. It can be calculated in units of R-cm²/mCi-hr using one of the following two equations which were derived (*6,7*) taking 33.73 eV as the energy required to produce an ion pair.

$$\Gamma = 1.51 \times 10^5 \, \Sigma n_i E_i \, (\mu_a)_i \qquad (1)$$

and

$$\Gamma = 195.1 \, \Sigma n_i E_i \, (\mu_{a/\rho})_i. \qquad (2)$$

Both the equations are essentially the same. They can be used depending on the accessibility of the values of μ_a (linear energy-absorption coefficient in air per cm) and $\mu_{a/\rho}$ (mass energy-absorption coefficient in air in cm²/gm). These values can be obtained from Evans (*7*) and *Radiological Health Handbook* (*8*). The mean number of emissions per disintegration (n_i) and the corresponding energy in MeV (E_i) can be obtained from *Radiological Health Handbook* (*8*), and Lederer et al (*9*). Table 1 summarizes these parameters for the calculation of Γ for ^{135m}Ba. The calculated values for Γ were 0.594 and 0.593 (R-cm²/mCi-hr) from Eqs. 1 and 2, respectively.

The value of Γ is useful for the calibration of instruments for the assay of gamma-ray emitting radionuclides. Mercury-203 can be used as a reference source for the assay of ^{135m}Ba because they have similar photon energies. The value of Γ for ^{203}Hg was calculated to be 1.318 (R-cm²/mCi-hr) using the present method. The ratio of this Γ to that of ^{135m}Ba is 2.22. We have used this factor for the assay of ^{135m}Ba radioactivity using a commercially available radionuclide dose calibrator and an ionization chamber.

EQUILIBRIUM ABSORBED-DOSE CONSTANT AND DOSIMETRY

The values of Δ_i, the equilibrium absorbed-dose constant, for ^{135m}Ba were arrived at on the basis of information obtained from Lederer et al (*9*), *Radio-*

Received Dec. 30, 1970; revision accepted April 29, 1971.

For reprints contact: F. Hosain, The Johns Hopkins Medical Institutions, Dept. of Radiological Science, 615 N. Wolfe St., Baltimore, Md. 21205.

TABLE 1. PARAMETERS FOR CALCULATING Γ FOR ^{135m}Ba

Radiation (i)	Photon yield (n_i)	Energy in MeV (E_i)	$(\mu_a)_i$(cm^{-1}) $\times 10^5$	$(\mu_{a/\rho})_i$(cm²/gm)
Gamma-1	0.1494	0.2680	3.67	0.0280
K α-1 x-ray	0.2691	0.0322	15.77	0.1220
K α-2 x-ray	0.1397	0.0318	16.29	0.1260
K β-1 x-ray	0.0759	0.0364	11.14	0.0862
K β-2 x-ray	0.0161	0.0374	10.14	0.0805

TABLE 2. VALUES OF Δ_i FOR VARIOUS EMISSIONS OF ^{135m}Ba

Radiation (i)	Mean number per disintegration (n_i)	Mean energy (MeV) ($\bar{E}_i$)	Δ_i (gm-rad/μCi-hr)
Gamma-1	0.1494	0.2680	0.0853
K int. con. electron, gamma-1	0.5672	0.2310	0.2790
L int. con. electron, gamma-1	0.2127	0.2624	0.1188
M int. con. electron, gamma-1	0.0709	0.2669	0.0403
K α-1 x-rays	0.2691	0.0322	0.0184
K α-2 x-rays	0.1397	0.0318	0.0094
K β-1 x-rays	0.0759	0.0364	0.0058
K β-2 x-rays	0.0161	0.0374	0.0012
L x-rays	0.1165	0.0045	0.0011
KLL Auger electrons	0.0437	0.0263	0.0024
KLX Auger electrons	0.0194	0.0308	0.0012
KXY Auger electrons	0.0033	0.0353	0.0002
LMM Auger electrons	0.6117	0.0034	0.0044
MXY Auger electrons	1.5127	0.0011	0.0035

logical Health Handbook (*8*), and the Oak Ridge National Laboratory. The nuclear parameters are presented in Table 2 in the same format as published in MIRD pamphlets for other radionuclides. A value of 0.4507 was obtained from the table for $\Sigma\Delta_i$ for the nonpenetrating radiation. An approximate value of 0.446 can be obtained without the table by multiplying 2.13 by $n_e\bar{E}_e$ (*10*), the average energy per disintergration deposited in the vicinity of the nuclide, formerly known as $\bar{E}_\beta$.

Barium-135m is a bone-seeking element, and the skeleton is the critical organ. The absorbed radiation doses due to intravenously administered ionic ^{135m}Ba were calculated for the total body and the skeleton. The values of absorbed fraction (ϕ_i) were obtained from MIRD Pamphlet 5 (*11*). The values of $\Sigma(\Delta_i\phi_i)$ were found to be 0.5085 and 0.4842 for the total body and the skeleton, respectively. The effective half-life was taken equal to the physical half-life of ^{135m}Ba. It was assumed that 100% of the dose was distributed uniformly in the total body of a 70-kg man with 10-kg skeleton. Skeletal uptake was taken as 60% (*5*) and assumed to be uniformly distributed. The radiation doses were estimated to be 0.3 and 1.2 rads/mCi for the total body and the skeleton, respectively.

SUMMARY

Barium-135m, a potential radionuclide for bone scanning, has a half-life of 28.7 hr and emits 268-keV photons. The specific gamma-ray constant (Γ) was calculated. Methods of source calibration have been presented. The equilibrium absorbed-dose constant has been calculated and the radiation doses are 0.3 and 1.2 rads/mCi for the total body and the skeleton, respectively.

ACKNOWLEDGMENTS

The authors wish to thank Henry N. Wagner, Jr. This study was supported by U. S. Public Health Service Grant GM-10548.

REFERENCES

1. KNISELY RM, ANDREWS GA, EDWARDS CL, et al: Bone marrow and skeletal scanning. *Radiol Clin N Am* 7: 265–280, 1969

2. HOSAIN F, SYED IB, WAGNER HN, et al: Ionic ^{135m}Ba for bone scanning. *J Nucl Med* 11: 328, 1970

3. LANGE RC, TREVES S, SPENCER RP: ^{135m}Ba and ^{131}Ba as bone scanning agents. *J Nucl Med* 11: 340–341, 1970

4. SUBRAMANIAN G: ^{135m}Ba: preliminary evaluation of a new radionuclide for skeletal imaging. *J Nucl Med* 11: 650–651, 1970

5. HOSAIN F, SYED IB, WAGNER HN, et al: Ionic barium-135m, a new agent for bone scanning. *Radiology* 98: 684–686, 1971

6. MITCHELL TG: The dosimetry of internally administered radionuclides. In *Atomic Medicine*. Behrens CF, King ER, Carpender JWJ, eds. Baltimore, Williams & Wilkins Co., 1969, p 472

7. EVANS RD: X-ray and gamma-ray interaction. In *Radiation Dosimetry*, vol I, Attix F, Roesch W, eds. New York, Academic Press, 1968, pp 93–155

8. *Radiological Health Handbook*, compiled and edited by the Bureau of Radiological Health, USDHEW, Rockville, Md, 1970

9. LEDERER CM, HOLLANDER JM, PERLMAN I: *Tables of Isotopes*. New York, John Wiley & Sons, 1968

10. SMITH EM, BROWNELL GL, ELLETT WH: Radiation Dosimetry. In *Principles of Nuclear Medicine*. Wagner HN, ed, Philadelphia, W. B. Saunders Co, 1968, p 761

11. SNYDER WS, FORD MR, WARNER GG, et al: Estimates of absorbed fractions for monoenergetic photon sources uniformly distributed in various organs of a heterogeneous phantom. MIRD Pamphlet No 5, *J Nucl Med* 10: Supplement No 3, 36–37, 1969