〈論 文〉

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A Study on Bioassay of Tritium(^3H) Radioacitivity

三重水素(^3H) 放射能의 生理分析에 關한 硏究

Sun-Tae Hwang, Pil Jae Oh, Wŭon-Shik Kim
黃 善 泰* 吳 必 濟* 金 源 植*

초 록

삼중수소(^3H)에 관한 환경 및 생물학상의 연구는 1950년대 중반부터 선진국에서 수행되오고 있다. 삼중수소에 대한 잠재적 노출의 경우 통상적 처리절차는 삼중수소의 신체부하량이라고 일컬어지는 이른바 신체내에 축적된 삼중수소의 양을 결정하기 위하여 삼중수소수로서 오줌속에 포함되는 삼중수소 방사능의 생리분석이다.

전신에 있어서 삼중수소의 최대허용신체부하량은 신체조직에 대하여 약 $30\mu Ci/\ell$ 이다.[1] 생리분석에서 오줌속에 삼중수소를 검출하는데 가장 보편적인 조사준위(照射準位)는 최대허용신체부하량의 1/10이다.

이러한 생리분석 연구계획을 위해서는 소광보정(消光補正) 곡선을 그리는 것이 가장 우선적이다. 이것은 검뇨용 오줌의 색깔이 일정하지 않기 때문에 필요한 것이다. 이 경우에서 소광효과는 주로 오줌시료에 의한 섬광빛의 흡수에 기인된다.

소광보정곡선으로 판단된 공식은 통계적 근거에서 최소자승법에 의하여 $Y(\%) = 0.771 + 1.836 \times 10^{-4} X(count)$로 얻어졌다. 여기서 Y는 섬광계수 효율로서 약 12 %에서 31 % 범위의 값으로 나타났다.

본 논문에서는 삼중수소의 생물학적 반감기와 신체계통적으로 분포된 삼중수소에 적용되고 있는 정체(停滯) 공식에 관한 간략한 이론에 관하여 서술된다.

ABSTRACT

The environmental and biological studies of tritium have been carried out in the advanced countries since the mid 1950's. In the case of a potential tritium exposure, the usual procedure is tritium bioassay (as HTO) in human urine in order to determine the amount of tritium deposited in the body called tritium body burden.

The maximum permissible body burden (MPBB) of tritium in total body is about $30\mu Ci/\ell$ for body tissue.[1] In the bioassay, the most common investigation level for detection of tritium in urine is 1/10th of MPBB.

* 韓國標準硏究所 放射線硏究室 Korea Standards Research Institute, Taejon, Korea.

For this bioassay project, the first priority is given to obtaining a quench correction curve. This consideration is necessary because of the variability in color of human urine specimens. Quenching effect in this case mainly is caused by the absorption of scintillation light flashes by the urine sample.

By the least squares method on the statistical basis, an estimated formula for quench correction curve was determined to be $Y = 0.771 + 1.836 \times 10^{-4} X$, where the efficiency (Y) was ranged from about 12% to 31% in the liquid scintillation counting.

In this paper, a brief theory concerning the biological half-life of tritium and the retention formula to apply to systematically dstributed tritium are described.

INTRODUCTION

Tritium (^3H), a radioisotope of hydrogen is commonly used as a tracer for hydrogen in biological and chemical studies. Most hazards attendant on the handling of this isotope are limited to those from radiations from internally deposited sources because tritium emits an unusually soft beta particle with a maximum energy of approximately 0.0186 MeV and average energy of 0.0057 MeV.

With the widespread use of tritium in research applications related to the life sciences, an efficient bioassay procedure is needed for the rapid evaluation of the health hazard resulting from the accidental tritium exposure. However, the detection of tritium in human urine by the radioassay poses some difficult problems. They are mainly self-absorption and possible quenching effects because of the low energy of its beta-emission To minimize these problems, therefore, urine samples are usually analyzed by liquid scintillation counting method.

According to Davidson and Feigelson,[2] the liquid scintillation counting began in 1950 when G.T. Reynolds et al. and H. Kallman independently reported that dilute solutions of certain substances in aromatic solvents could be used with photomultiplier tubes to detect radiation.

For measuring low-energy beta emitter such as tritium, the general principle of liquid scintillation counting method have been well reviewed by Hayes.[3]

Biological Half-life

When tritium is introduced into the body by the three possible routes of entry – inhalation, ingestion, and percutaneous absorption, the radioisotope uniformly distributes itself throughout the body water.[4] Thus, provided that the water intake is not too rapid to permit equilibrium with all body water, the concentration of tritium in the urine is equal to that in the body water.

If the concentration is determined at periodic interval following the initial exposure, it is possible to determine the biological half-life and the resultant body dose.

In general, assuming the activity per unit volume of urine at any time, A_t, then the following relationship is given:

$$A_t = A_0 \cdot e^{-(\lambda_p + \lambda_b)t} \quad (1)$$

where, A_0 = the initial postulated tritium activity per unit volume of urine ($\mu Ci/\ell$),

λ_p = the physical decay constant (d^{-1}),
λ_b = the biological decay constant (d^{-1})
t = the elapsed time after exposure to tritium (d).

From Eq. (1),

$$\lambda_p + \lambda_b = (1/T_p + 1/T_b)\,\ell n 2 \qquad (2)$$

where, T_p = the physical half-life,
T_b = the biological half-life.

For tritium, T_p is 12.33 years which makes $1/T_p$ comparatively negligible to $1/T_b$.

Therefore, $A_t \simeq A_o \cdot e^{-0.693/T_b}$ (3)

In the 1959 publication of ICRP,[5] a conservative value of 12 days has been adopted as the biological half-life of tritium. More recently, Butler and Leroy group's studies[6] have shown that the biological half-life values range from 4 to 18 days, with an average of 9.5 ± 4.1 days at the 90% confidence level.

The potential hazard of radioisotope tritium deposited in the human body is dependent on its effective biological half-life, amount of tritium assimilated, and retention, excretion characteristics. For an example, from the human tritium excretion studies following accidental exposure to it, Snyder et al.[7] drew a formula for tritium concentration in urine as follows:

$$R(t) = 5.3 \times 10^6 \cdot e^{-\lambda_1 t} + 2.3 \times 10^4 \cdot e^{-\lambda_2 t} \qquad (4)$$

where, λ_1 = 0.693/8.7 and λ_2 = 0.693/34 for t in days. This retention formula indicates the presence of two retention components for uniformly distributed tritium in a human body. However, a more general retention formula in radioassay is of the form,

$$R(t) = \sum_{i=1}^{n} f_i \cdot e^{-\lambda_i t}, \quad n \geqq 2 \qquad (5)$$

where, f_i, λ_i = constants obtainid from the retention curve by its graphic analysis.

Objectives

The two most common forms of tritium encountered in the laboratory environment are tritium gas and tritiated water. Actually, the extent of radiological hazard from tritium depends upon its chemical form and the routes of entry into the body.[8]

It is believed that tritiated water introduced into the body becomes a part of the general pool of body water and that continuous exposure to tritium gas in air will result in reaching a concentration in the lungs similar to that in air. Hence, the tritium bioassay studies are undertaken primarily to evaluate the possible health hazards to personnel in the laboratories who might be exposed to tritium either chronically or acutely. The principal evaluation procedure involves a study of tritium activity in urine sample utilizing the quench correction curve to determine the counting efficiency and thus to estimate tritium body burden.

METHOD AND RESULT

In the experiments using liquid scintillation counters, the accuracy of urinalysis depends largely upon the determination of counting efficiency. The most common methods used to determine sample counting efficiency are (a) the internal standard method, (b) the channels ratio method, (c) the external standard method.[9] The main advantages of these methods are that its determination allows the conversion of counting data into the absolute unit, disintegrations per minute (dpm) by dividing the net counts per minute by the corresponding efficiency of the scintillation counter.

The present study reports that urine samples

are conveniently analyzed by the liquid scintillation counting method even though the color and acidity of raw-urine can affect the counting efficiency. In particular, a method is described here by which the counting efficiency can be determined from the counts given by the interactions with gamma-rays from the automatic external source using scintillation fluid, AQUASOL and tritiated urine which is contained in this fluid.

In liquid scintilaltion counting (LSC), first of all, a LSC vial is prepared with one milliliter of uncontaminated raw-urine and ten milliliters of AQUASOL fluid to serve as the background counting source. Next, ten each, low background, glass vials are labeled "1", "2", "3", ..., and "10". (Other labels of choice may be substituted by those preferring something more convenient). After this step, one milliliter of tritiated raw-urine which has activity of 2063 disintegrations per minute is added to each of the ten vials. On completion of these preparations, all of the vials are placed in the scintillation counter and counted for ten minutes after cooling them for a while.

After the ten minute counting, small quantities of a solution of yellow colored food-dye in raw-urine is added to each of the ten vials as soon as possible. The quantity of food-dye solution added to each vial varies from one vial to another. Again all of these vials are placed in the counter and are counted for ten minutes, too. The same procedures can be performed after this step in like manner if necessary. Usually, the procedure of adding the food-dye solution is performed two or three times. Thus, this procedure is followed to obtain data that will be representative of urine specimens that may be collected from a variety of people under different conditions.

From these procedures, a quench correction curve as shown in Figure 1 was obtained by using the least squares method. The Packard Tri-Carb liquid scintillation spectrometer (Model 3330) employed in this study has three SCA's and three scalers that is enable this counter to count three different parts of pulse height spectrum.

When the tritiated raw-urine is added to the scintillation fluid, the scintillation process is usually quenched to some degree, resulting in a certain loss of counting efficiency because of color and chemical quenching. In spite of different quenching degrees from one sample vial to another, however, the counting efficiencies can be determined by the activity of original tritiated raw-urine.

CONCLUSIONS AND DISCUSSION

Figure 1 presents the data being related to the counting efficiency of scintillation counter for tritiated raw-urine samples. The accuracy of the quench curve determined in this experiment is quite dependable from its evaluations. That is, it is found that the tritium activity of a known sample estimated by using the formula for quench curve shows only 0.4% – 0.5% differences from the expected activity obtained by the direct calculation method.

Therefore, provided that the tritiated raw-urine samples had been prepared correctly and that the related statistical errors had not been significant in this study, then the quench curve in Figure 1 can be satisfactorily used for estimation of tritium activity of any unknown urine specimen.

With regard to human health and safety, however, it is necessary that we determine "how much dose is the estimated tritium activity in a urine specimen correspondent to?" From this information, short term as well as long term exposures for people who provided his urine sample should be figured out.

For this particular matter, the Medical

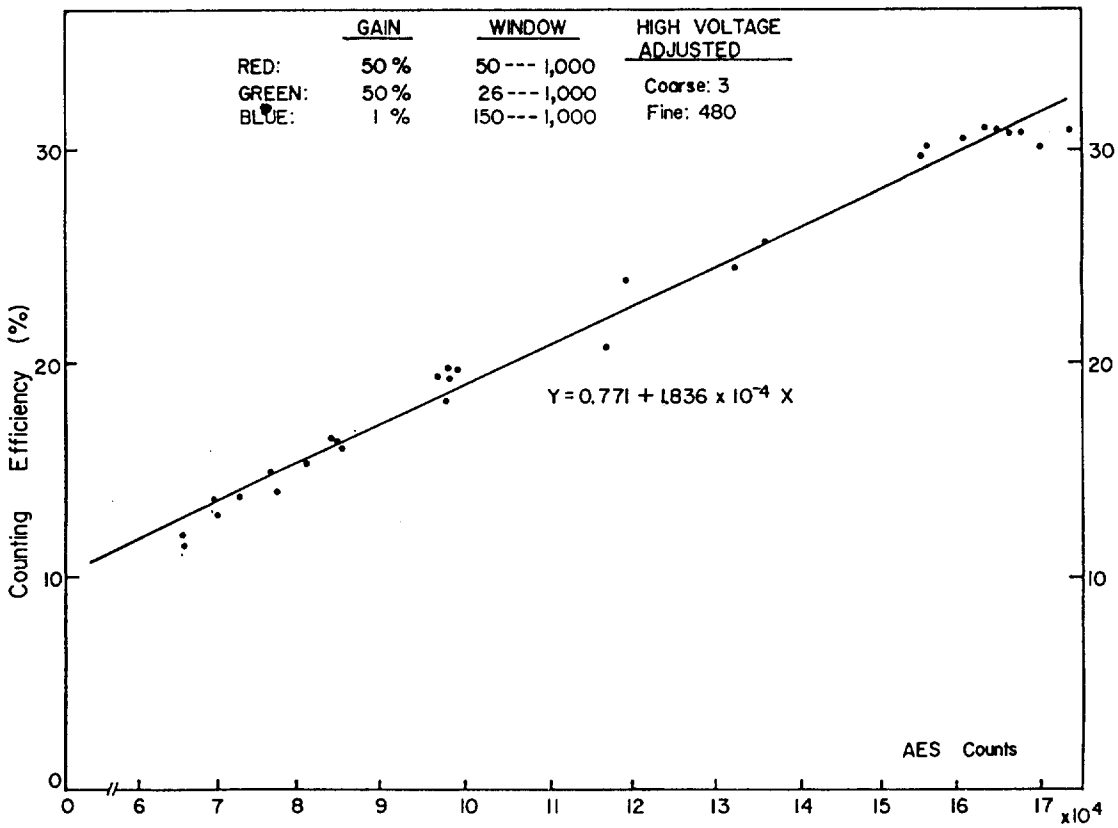

Figure 1. Quench Correction Curve for Tritium

International Radiation Dose Committee (MIRD) has developed basic equations for calculating the absorbed dose to a man from a radiopharmaceutical to evaluate the relative risk versus its benefit.

The actual calculation of absorbed dose is based upon the basic schema proposed by Loevinger and Berman [10] in MIRD Pamphlet No. 1. For the complete determination of absorbed dose, the additional refinements by Cloutier et al. [11] are suggested.

Nuclear Data for ^3H

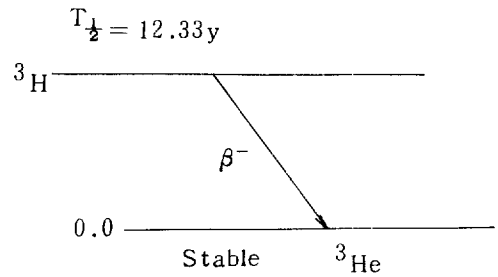

Figure 2. ^3H decay scheme

(a) n_i = 1.0000
Mean Number/Disintegration

(b) E_i = 0.0057 MeV
Mean Energy/Particle

(c) $\triangle_i$ = 0.0121 g-rad/μCi-h
Equilibrium Dose Constant

12)

Absorbed Dose Equations

The calculations are based on the following basic equations: [10, 13]

$$\bar{D}(r_k \leftarrow r_h) = \frac{\tilde{A}_h}{M_k} \sum_i \triangle_i \cdot \phi_i (r_k \leftarrow r_h) \quad (6)$$

$$S(r_k \leftarrow r_h) = \sum_i \triangle_i \cdot \phi_i (r_k \leftarrow r_h) \quad (7)$$

From the relation between Eqs. (6) and (7), we have

$$\bar{D}(r_k \leftarrow r_h) = \frac{\tilde{A}_h}{M_k} S(r_k \leftarrow r_h) \quad (8)$$

where, $\bar{D}$ = the mean absorbed dose (rad) for complete decay,

$(r_k \leftarrow r_h)$ = radiation direction from source organ, r_h to target organ, r_k,

$\tilde{A}_h$ = the cumulated activity (μCi-h) in the source organ,

M_k = the mass (g) of the target organ,

$\triangle_i$ = the equilibrium dose contant (g-rad/μCi-h),

ϕ_i = the absorbed fraction,

$S(r_k \leftarrow r_h)$ = the mean absorbed dose per unit cumulated activity. [14]

On the other hand, since the dose equivalent (DE) is the product of absorbed dose in rads and a quality factor (QF), we obtain

$$DE\ (rems) = D \times QF \quad (9)$$

Quality factor for tritium beta particle with $E_{max} < 0.03$ MeV is 1.7. [15] Thus, we can draw the conclusion as follow:

$$\overline{DE}\ (rems) = 1.7 \times \bar{D}\ (rads) \quad (10)$$

As the result of Eq. (10), we can calculate the actual total body dose in rems. The dose equivalent reflects a recognition of differences in the effectiveness of different radiations to inflict overall biological effect.

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