GEORGIA INSTITUTE OF TECHNOLOGY

The George W. Woodruff School of Mechanical Engineering

NRE/HP Qualifier Exam

Fall Semester 2000

_____Your ID Code

Day 2 – Special

Instructions

1. **Use a separate page for each answer sheet (no front to back answers).**

2. **The question number should be shown on each answer sheet.**

3. **Answer 4 of the 6 questions.**

4. **Staple your question sheet to your answer sheets and turn in.**

1. The radionuclides Sr-89 and Sr-90 must be measured in a sample of vegetables.

   a. Outline a procedure for radiochemical analysis and radiation detection to determine the two radionuclides in the presence of other radionuclides. Sr-89, Sr-90, and its progeny Y-90, emit only beta particles.

   b. Briefly describe a quality assurance program for the laboratory and counting room in which the analyses are performed.

   c. The samples are counted for radiostrontium 30 days after collection and 24 hours after separation of strontium from all other elements. Calculate the count rates of each of the three radionuclides in counts per second if the initial sample contained 10 Bq Sr-90 and 20 Bq Sr-89.

Radionuclide	Half-Life	Counting Efficiency
Sr-90	28y	30%
Y-90	64h	40%
Sr-89	50d	35%

2. A large community hospital wishes you to set up a personnel monitoring program. The following organization information is provided:

Department A: The nuclear medicine department is a well-equipped department using technetium-99m for all its studies. The Tc-99m is milked from a generator and the radiopharmaceuticals are prepared within the nuclear medicine department. The department has sealed sources of cobalt-57, cesium-137, and barium-133 for calibrating the dose calibrator.

Department B: The x-ray department is an active group using fluoroscopic procedures, general diagnostic x-ray procedures, and some special procedures.

Department C: The radiation therapy department is an active group using a Co-60 teletherapy device and a 4.0-MeV linear accelerator, but no brachytherapy.

Department D: The research department is a fairly active group using only hydrogen-3 and carbon-14.

Answer the following questions. Justify your answers.

a. What departments will require personnel monitoring for photons?
b. What department will require personnel monitoring for neutrons?
c. What departments will benefit from both a personnel monitor at the belt (under leaded apron) and one at the collar?
d. What department would need ring badges?
e. In what department would the assessment of skin dose be important?
f. What department might require bioassay?
g. List a positive and negative characteristic of film dosimeters for personnel monitoring.
h. List positive and negative characteristics

3. In monitoring for airborne ^{32}P (half-life = 14.26 days, a beta emitter, E_{ave} = 0.695 MeV, 100%), an air sample of 5.0 m^3 volume is taken. The first measurement made 5 hr after collection gives 4200 counts in 20 min. A 20-min background count gave 1000 counts. The sample was counted again 24 hr later and gave 2400 counts in 20 min; a background count of 52 counts/min. If the filter was counted in a windowless 2π gas-flow counter, what was the mean concentration of ^{32}P in the air? (^{212}Pb half-life = 10.6 hrs. The limiting activity in ^{222}Rn daughter chain: ^{214}Pb, half life = 26.8 min. The limiting activity in ^{220}Rn daughter chain: ^{212}Pb, half life = 10.6 hr.)

4. A worker is checked by whole-body counting for internal radionuclide contamination due to Cs-137 and I-131.

   a. Briefly discuss the type of detector used and what measurements must be performed before counting the worker to determine the activity of the radionuclides in a body and the lower limit of detection. How does one optimize detection sensitivity?

   b. The worker was counted for 1,000 seconds under the conditions listed. Calculate the body burdens of the two radionuclides in Bq and the standard deviation of the results. Determine whether the results are above the detection limit, defined as the 2-sigma value of the results.

Radionuclide	**Counting Efficiency***	**Background Count Rate**	**Gross Count Rate**
Cs-137	0.13%	1.5 s^{-1}	2.5 s^{-1}
I-131	0.10%	3.0 S^{-1}	3.1 s^{-1}

* Includes correction for photon fraction.

5. A graphite-moderated reactor is cooled by passing air at the rate of 680.000 kg/h through the core. The mean temperature in the core is 300°C and the thermal neutron flux is 5×10^{13} neutrons/cm^2/s.

   a. If the air spends an average of 10 s in the reactor core, what is the rate of production of ^{41}Ar?

   b. If the chimney through which the air is discharged is 100 m high and has an orifice diameter of 2 m and the temperature of the effluent air is 170°C, while the ambient temperature is 30°C on a sunny day and if the mean wind velocity is 2 m/s, at what distance from the chimney will the ground-level concentration of ^{41}Ar be a maximum?

   c. What will be the value of this maximum concentration (in Bq/m^3)? How does this concentration compare to the DAC for ^{41}Ar (0.1 μ Bq/m^3)?

Useful:

$$\chi(x, y) = \frac{Q}{\pi\sigma_y\sigma_z u} e^{-\frac{1}{2}\left(\frac{y^2}{\sigma_y^2}+\frac{H^2}{\sigma_z^2}\right)}$$

effective stack height: $H = h + d\left(\frac{v}{u}\right)^{1.4}\left(1 + \frac{\Delta T}{T}\right)$

where h = actual chimney height, meters
d = chimney outlet diameter, meters
v = exit velocity of gas, meters per second
u = mean wind speed, meters per second
ΔT = difference between ambient and effluent gas temperatures (°K)
T = absolute temperature of effluent gas (°K)

It may be of assistance to assume $\sigma_y = a\sigma_z$ where *a* is a constant.

(2 Attachments)

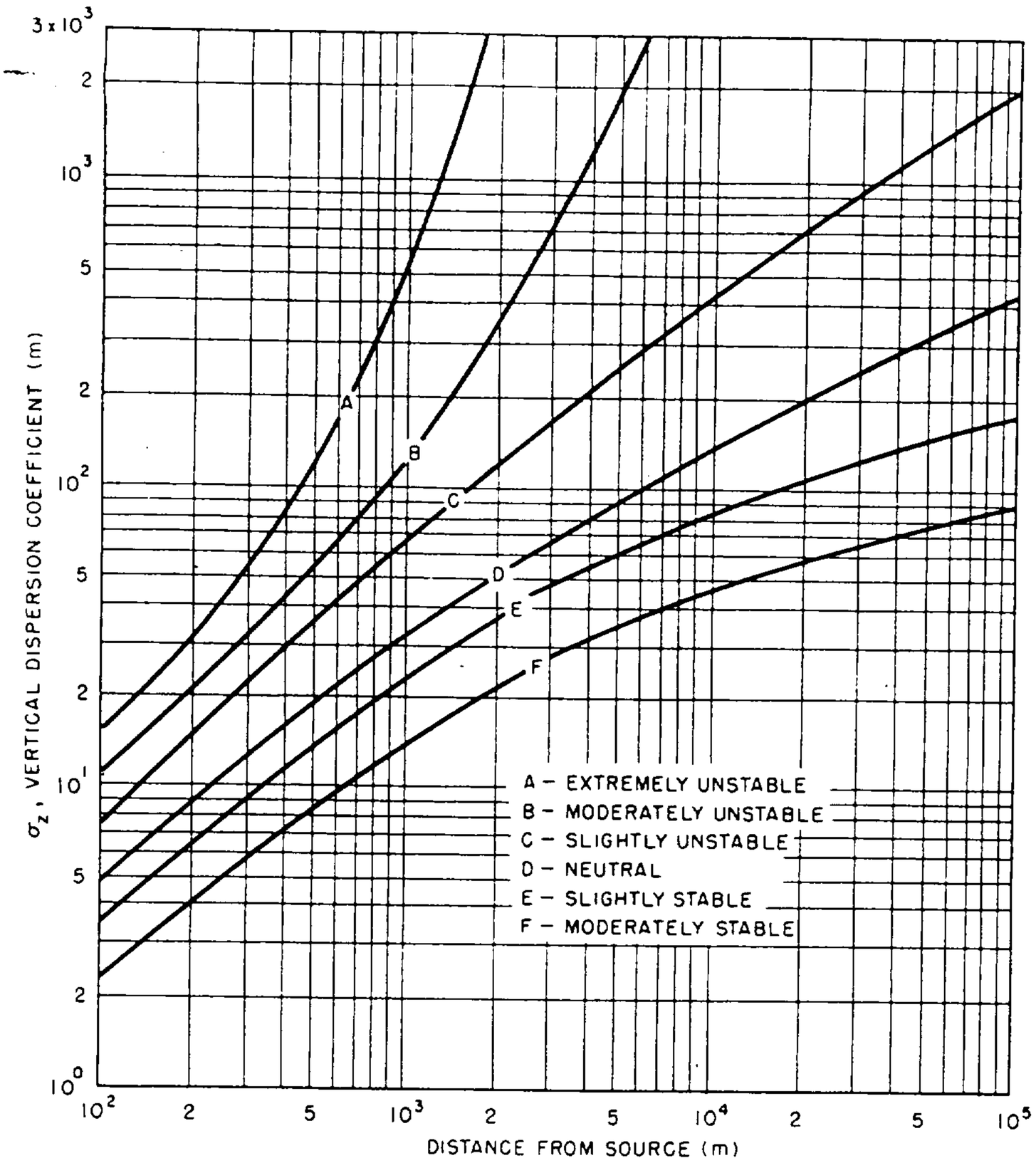

Fig. 3.11 — Vertical diffusion, σ_z, vs. downwind distance from source for Pasquill's turbulence types.

Pasquill stability categories	σ_θ
A, extremely unstable	25.0°
B, moderately unstable	20.0°
C, slightly unstable	15.0°
D, neutral	10.0°
E, slightly stable	5.0°
F, moderately stable	2.5°

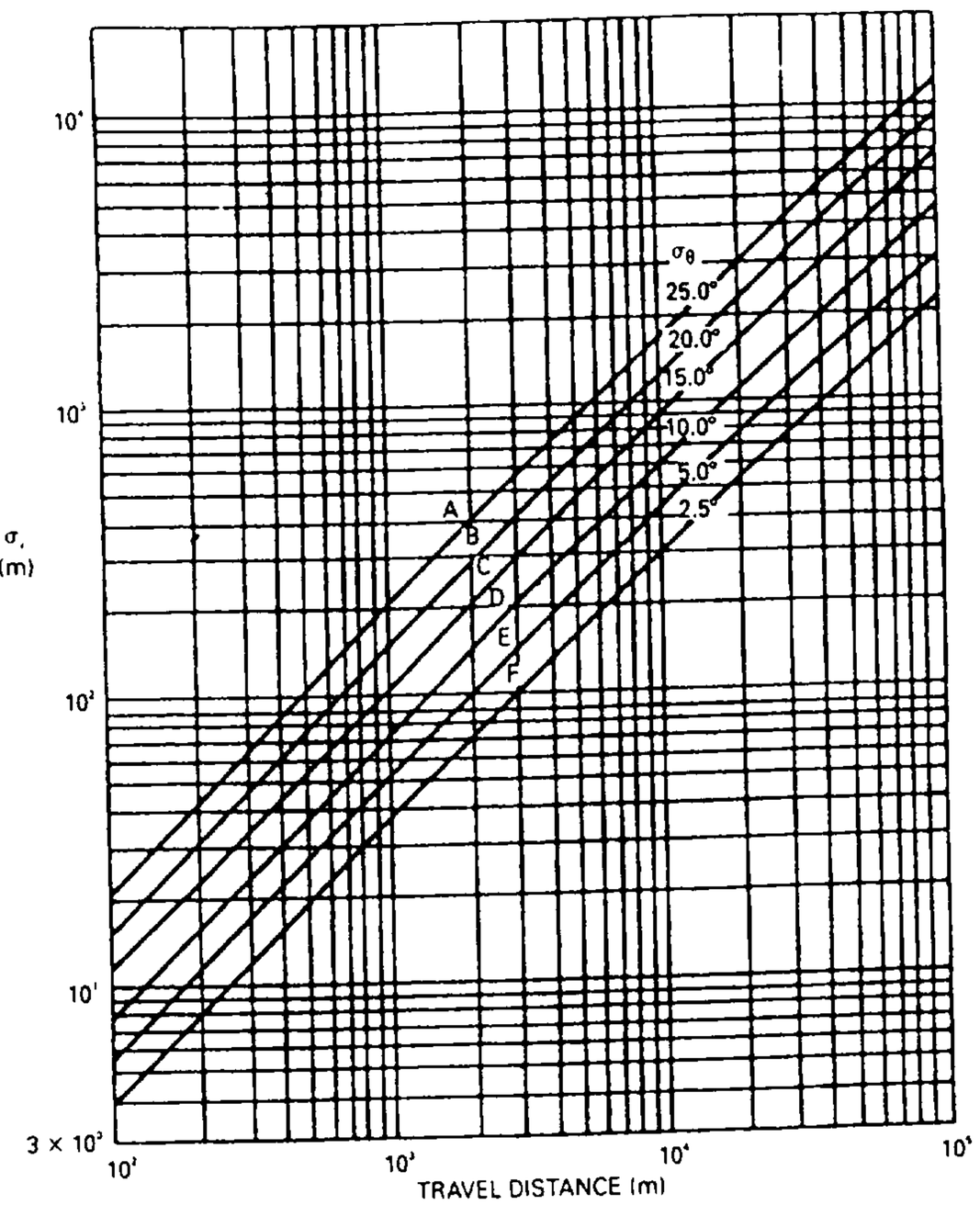

TABLE 11.10. Pasquill's Categories of Atmospheric Stability

A: Extremely unstable conditions
B: Moderately unstable conditions
C: Slightly unstable conditions
D: Neutral conditions[a]
E: Slightly stable conditions
F: Moderately stable conditions

Surface Wind Speed, m/s	Daytime Insolation			Thin Overcast or ≥ 4/8 Cloudiness[b]	≤ 3/8 Cloudiness
	Strong	Moderate	Slight		
<2	A	A–B	B		
2	A–B	B	C	E	F
4	B	B–C	C	D	E
6	C	C–D	D	D	D
>6	C	D	D	D	D

[a]Applicable to heavy overcast, day or night.
[b]The degree of cloudiness is defined as that fraction of the sky above the local apparent horizon which is covered by clouds. (Manual of Surface Observations [WBAN], Circular N [7th ed.], paragraph 1210. U.S. Government Printing Office, Washington, July 1960.) (From W. F. Hilsmeier, F. A. Gifford, Jr., *Graphs for Estimating Atmospheric Dispersion*. Report ORO-545. Oak Ridge National Laboratory, Oak Ridge, Tenn., 1962.)

6. A male worker is accidentally exposed to airborne tritium in water-vapor form for a period of 30 minutes. This exposure occurred beginning at 8:00 a.m. on a Friday. Starting at 8:00 a.m. on Monday, the worker's urine was collected for 24 hours. The specific activity in the urine was 120 Bq/g. Assume that the worker's daily water intake increased to 6000 mℓ after the accident. Estimate the concentration (Bq/m^3) of tritium in the atmosphere to which the worker was exposed and the soft-tissue committed dose equivalent (Sv) incurred as a result of the exposure.

   Data:

   i. radiological half life of ^3H = 12.3 year
   ii. beta energy (max.) = 0.0186 MeV, yield = 100%
   iii. attached metabolic data for hydrogen (ICRP 30, Part I)

(2 Attachments)

METABOLIC DATA FOR HYDROGEN

1. Metabolism

Data from Reference Man (ICRP, 1975)

Hydrogen content of the body	7 000 g
of soft tissue	6 300 g
Daily intake of hydrogen	350 g
Water content of the body	42 000 g
Daily intake of water, including water of oxidation	3 000 g

For a number of soft tissues water comprises about 80 % of the mass.

2. Metabolic Models

(a) *Elemental tritium*

As discussed in Chapter 8 of this report, exposure to elemental tritium in air is limited by consideration of the total dose equivalent received from tritium contained in the lung during any year of practice.

It is emphasized that the limit on exposure to tritiated water is more than four orders of magnitude less than that for elemental tritium and in most cases in practice exposure to tritiated water will be the limiting factor.

(b) *Tritiated water*

(i) *Ingestion.* Ingested tritiated water is assumed to be completely and instantaneously absorbed from the gastrointestinal tract and to mix rapidly with the total body water so that, at all times following ingestion, the concentration in sweat, sputum, urine, blood, insensible perspiration and expired water vapour is the same (Pinson and Langham, 1957).

(ii) *Inhalation.* Exposure to an atmosphere contaminated by tritiated water results in intake of that substance both by inhalation and by absorption through the intact skin.

Osborne (1966) has shown that exposure to an atmosphere contaminated by tritiated water at a concentration of C Bq m^{-3} results in the absorption of 10^{-2} C Bq min^{-1} through the intact skin. For Reference Man (ICRP, 1975) breathing air at a rate of 0.02 m^3 min^{-1} the rate of inhaling tritiated water is 2×10^{-2} C Bq min^{-1} and it is assumed that all of this is absorbed into body fluids. Therefore the total rate of absorption of tritiated water into body fluids is 3×10^{-2} C Bq min^{-1} or 3.6×10^{3} C Bq in a working year of 2 000 h. It is assumed that this tritiated water is instantaneously distributed uniformly among all the soft tissues of the body.

(iii) *Distribution and retention.* Data on many humans have indicated that the retention of tritiated water is essentially described by a single exponential over the first months or more (Pinson and Langham, 1957). However, cases have been reported where a second exponential term or even a third have been observed (Snyder *et al.*, 1968; Sanders and Reinig, 1968; Moghissi *et al.*, 1972)

$$\text{i.e. } R(t) = A\, e^{-0.693t/T_1} + B\, e^{-0.693t/T_2} + C\, e^{-0.693t/T_3}$$

The value of T_1 is closely related to the turnover of body water. Since this is closely related to fluid intake, considerable variation of T_1 is to be expected because of variation of personal

habits and ambient temperature (Wylie *et al.*, 1963; Butler and LeRoy, 1965). Values of T_1 have been observed in the range 4–18 days; a typical value is 10 days (Butler and LeRoy, 1965) and this is in agreement with the value obtained for Reference Man (ICRP, 1975) who has an intake of 3 000 g water per day and contains total body water of mass 42 000 g.

$$T_1 = 0.693 \times \frac{42\,000}{3\,000} \simeq 10 \text{ days}$$

The second and third exponential terms suggest the presence of tritium in compartments other than the body water, and indeed, organically bound tritium has been demonstrated in animals chronically exposed to tritiated water (Evans, 1969). However, it may be estimated from the data (Snyder *et al.*, 1968; Sanders and Reinig, 1968; Moghissi *et al.*, 1972) that such pools contribute of the order of 10% of the committed dose equivalent to the whole body deriving from an intake of tritiated water and they have been neglected in this report.

It is concluded that values of the committed dose equivalent to body tissues arising from an intake of tritiated water may be estimated from consideration of the retention of tritiated water alone. This view has been confirmed by several authors, e.g. Snyder *et al.* (1968) and Lambert and Clifton (1967).

Tritiated water is assumed to be uniformly distributed among all soft tissues at any time following intake and its retention to be described by a single exponential with a half-life of 10 days. Thus, the fraction of tritium, taken into the body as tritiated water, which is retained in the body t days later, is given by

$$R(t) = \exp(-0.693t/10)$$

and the concentration in soft tissue, C_s for a body content of q Bq is given by

$$C_s = q/63\,000 \qquad \text{Bq g}^{-1}$$

where 63 000 g is the mass of soft tissues in the body of Reference Man (ICRP, 1975).

(c) *Organic compounds*

(i) *Ingestion.* When tritium-labelled organic compounds are ingested, a considerable fraction may be broken down in the gastrointestinal tract producing tritiated water. Organic compounds of tritium may also catabolize to tritiated water after they have crossed the gut.

In rodents, more than 90% of tritiated thymidine is broken down in the gastrointestinal tract and only about 2% of the ingested substance is actually incorporated into DNA (Lambert and Clifton, 1968). The fraction of tritium incorporated into DNA after ingestion of tritiated thymidine is about one-fifth of that after the direct entry of tritiated thymidine into blood (Feinendegen and Cronkite, 1977). The fractional absorption of other nucleic acid precursors and of most other tritiated compounds into the blood is not known; in most instances it is probably greater than that of tritiated thymidine.

(ii) *Inhalation.* Many organic compounds of tritium are not very volatile under normal circumstances and the probability of their being inhaled as vapours is, therefore, small. In circumstances where they might be inhaled it would be prudent to assume that once they enter the lungs they are instantaneously and completely translocated to blood without changing their chemical form.

(iii) *Distribution and retention.* Tritiated organic compounds which are metabolic precursors are usually distributed throughout the soft tissues and only rarely specifically concentrate in particular cells. A notable exception is tritiated thymidine which, if not catabolized, is

taken up only by the nuclei of those cells synthesizing DNA. In mice, about 45% of all DNA-synthesizing cells in the body are located in the lining of the gastrointestinal tract, about 15% are found in the bone marrow and the rest are distributed mainly among spleen, lymphatic tissue, skin and parenchyma (Hughes *et al.*, 1964). These cells take up approximately 30% of the tritiated thymidine that enters the blood (Feinendegen *et al.*, 1973), and the clearance rate from the blood corresponds to a half-life of less than 1 h. Following ingestion, although the efficiency of incorporation of the compound is reduced by a factor of about 5, the relative distribution among the tissues and cells is considered to be similar to that after uptake from the blood (Feinendegen and Cronkite, 1977).

Some of the cells that incorporate tritiated thymidine into their DNA have a long life span of more than 10 days, renew themselves, and deliver a progeny of differentiated, functionally competent cells. It has been suggested that these are critical cells for the development of late radiation effects (Cronkite *et al.*, 1973).

Other tritiated compounds that serve as precursors for nucleic acids, are taken up in varying amounts by all nucleated cells in the body and thus become widely distributed throughout soft tissues. In mice these compounds were found to be incorporated from the blood into the tissues that contain large amounts of DNA-synthesizing cells less efficiently than tritiated thymidine (Feinendegen, 1978).

(iv) *Absorbed dose to tissues.* Average absorbed doses received by organs and tissues in experimental animals have been estimated for a number of organic compounds labelled with tritium; these include folic acid (Lambert and Clifton, 1967), thymidine (Lambert and Clifton, 1968), sex hormones (Vennart, 1969) and corticosteroids (Standeven and Clarke, 1967). Reports of these experiments were reviewed by Vennart (1969) who concluded that, under the radiological protection criteria then accepted, the maximum permissible annual intakes to blood of tritiated thymidine and tritiated folic acid should be about one-third of the maximum permissible annual intake of tritiated water, but that the maximum permissible annual intakes of tritiated sex hormones and tritiated corticosteroids should be about 30 times the maximum permissible annual intake of tritiated water. Consideration of absorbed dose to the cell nucleus (Berry *et al.*, 1966), of estimated biological effectiveness (Lambert, 1969; Bond and Feinendegen, 1966), and of the possibility that the long-lived self-renewing and DNA-synthesizing cells might be the critical cells (Feinendegen and Cronkite, 1977) indicate that the ALI to blood of tritiated thymidine should be about one-fourth to one-fiftieth of the ALI to blood of tritiated water. Furthermore the ALI by ingestion of tritiated thymidine might need to be one-tenth of that for tritiated water (Feinendegen and Cronkite, 1977).

In this report, specific values of ALI are not recommended for organic compounds of tritium but it is noted that they might differ considerably from those for tritiated water and that the value for tritiated thymidine might be as much as 50 times smaller. The exact ratio will depend on the compound and its route of entry into the body. This matter will be kept under review both with regard to any further indications of the relative effectiveness of these compounds as compared with tritiated water, and to their metabolism.

References

Berry, R. J., Oliver, R. and Reiskin, A. B. (1966). Reproductive death of mammalian cells due to beta radiation from incorporated thymidine labelled with ^{3}H or ^{14}C. *Health Phys.* 12, 1461–1466.

Bond, V. P. and Feinendegen, L. E. (1966). Intranuclear ^{3}H thymidine: dosimetric, radiological and radiation protection aspects. *Health Phys.* 12, 1007–1020.

Butler, H. L. and LeRoy, J. H. (1965). Observations of biological half-life of tritium. *Health Phys.* 11, 283–285.