CHAPTER 8

INTERNAL RADIATION HAZARDS

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1. If such sources are taken into the body, all of the radiation emitted is capable of interacting with the body.

2. The chemical properties of some radionuclides cause them to concentrate in certain body organs or tissues rather than be spread throughout the body. This leads to high local doses.

   Reasons (1) and (2) explain why the dose rate from sources within the body is much greater than from the same sources outside the body.

3. Internal sources irradiate the body 24 hours a day, seven days a week, until they have been eliminated from the body by excretion and decay.

4. Some radionuclides remain in the body for years.

5. It is often difficult to estimate the internal dose.

ENTRY OF RADIONUCLIDES INTO THE BODY

Radioactive materials may appear as solids, powders, dusts, liquids, gases, vapours or solutions. They may enter the body in three different ways:

1) Inhalation (breathing it),
2) Ingestion (eating it),
3) Absorption through the unbroken skin or through wounds.

Inhalation is most important

Soluble in body fluids?

Yes: "transportable".

Enter blood stream from lungs.

Deposit in body organs.

Eliminated in urine.

No: "non-transportable".

Retained in lungs.

Eliminated by ciliary action.

The tissue (which may be a body organ) in which radiation is absorbed is known as TARGET TISSUE.

The most important factors determining tissue dose are:

1) The amount of radioactive material deposited,

2) The length of time for which it is in the body,

3) The type and energy of the radiations emitted.

The BIOLOGICAL HALF-LIFE is the time taken for the amount of a particular element in the body to decrease to half its initial value due to elimination by biological processes alone.

The EFFECTIVE HALF-LIFE is the time taken for the amount of a specified radionuclide in the body to decrease to half its initial value as a result of <u>both</u> radioactive decay and biological elimination.

$$\lambda_e = \lambda_r + \lambda_b$$

$$1/T_e = 1/T_r + 1/T_b$$

FORM OF INTERNAL CONTAMINANTS

Particulates

Airborne fission and activation products attached to dust particles.

Gases

Usually fission product noble gases, xenon-133, xenon-135 and krypton-88, also argon-41. External radiation hazard only.

Vapours

Iodine vapour: target tissue = thyroid
Tritium vapour: target tissue = whole body

INTAKE is what you take in.

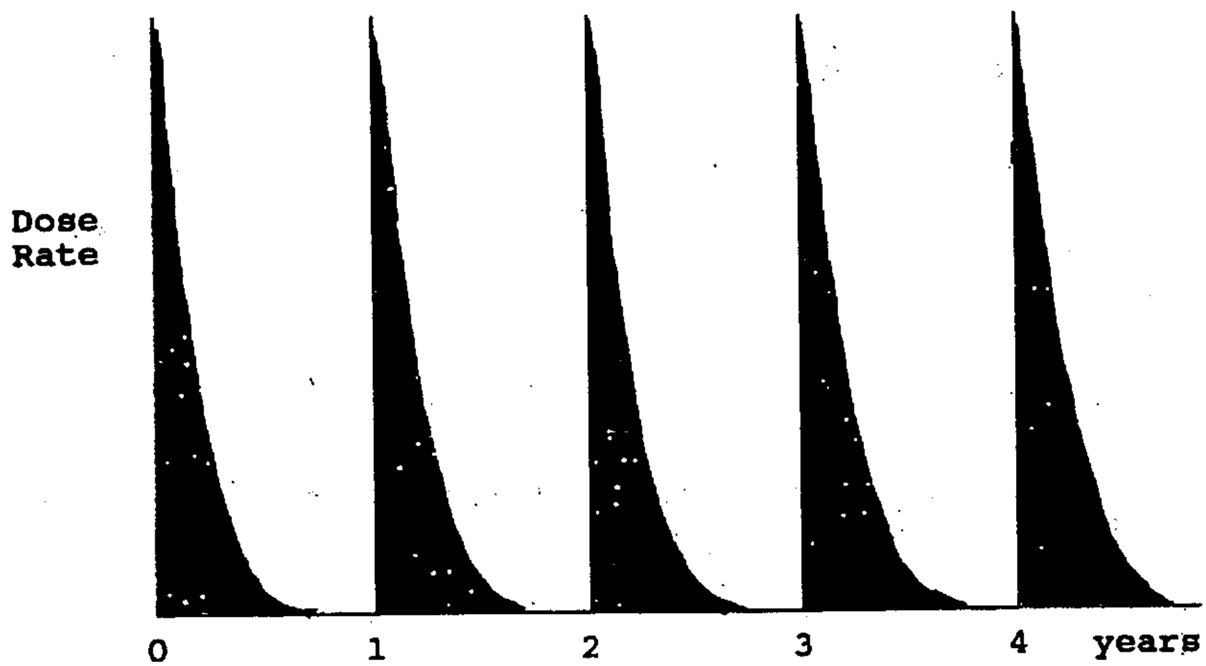
UPTAKE is what you keep

Reference Man

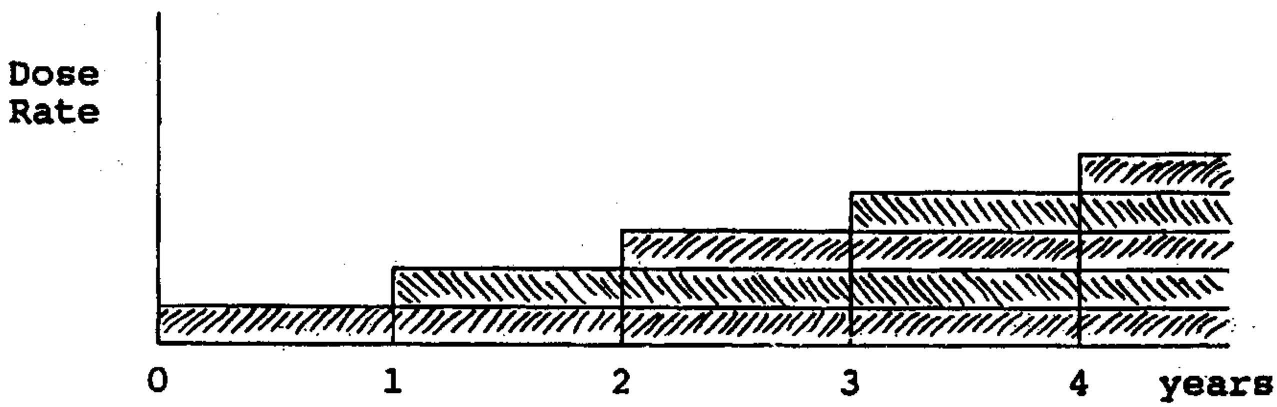
The ANNUAL LIMIT ON INTAKE (ALI) is the activity of a radionuclide that taken in by itself would commit a person, represented by Reference Man, to 20 mSv of weighted dose, H_W.

See Fig.8.1, p.314

Two values of the ALI for each radionuclide: inhalation and ingestion. Ingested materials are normally cleared from the body much faster than inhaled materials, so the ALI for the ingestion pathway is usually much larger than the ALI for the inhalation pathway.



I-131: Dosefrom 1 ALI taken in at the start of each year (H_T = 400 mSv; H_W = 20 mSv) is delivered in the year of intake, because the half-life is so short.



Pu-239: Dose from 1 ALI taken in at the start of each year (H_T = 2,000 mSv; H_W = 20 mSv) is delivered over many years, because the half-life is very long.

Fig. 8.1. Doses from 1 ALI of Different Radionuclides Will Be Delivered Over Different Times

THE DERIVED AIR CONCENTRATION

The permissible limit for inhalation of a radionuclide is the appropriate ALI. This is quoted in units of Bq.

We use the ALI to calculate the Derived Air Concentration (DAC).

The DERIVED AIR CONCENTRATION (DAC) for any radionuclide is that concentration in air (Bq/m^3) which, if you work in it for a year (50 weeks at 40 hours per week), will result in the ALI for inhalation.

The DAC is based on the breathing rate of Reference Man when he is engaged in "light activity" at work . This breathing rate is 0.02 m^3 of air per minute.

If we assume that your breathing rate at work is the same as Reference Man's you will breathe

0.02 m^3/min x 60 min/h x 2000 h/ y
= 2400 m^3 per year at work.

Therefore, if we divide the ALI by 2400 m^3, we get the Derived Air Concentration.

The ALI for a radionuclide depends on all of the following:

1) Type of radiation emitted.
2) Energy of the radiation emitted (including that of any radioactive daughters).
3) The selective deposition in specific body tissues.
4) The effective half-life.

Radio-nuclide	Radi-ation	ALI (Bq)	Target Tissue	H_T From 1 ALI	H_W From 1 ALI
H-3	β only	1E9	WB	20 mSv	20 mSv
I-131	β,γ	1E6	thyroid	400 mSv	20 mSv

Long-lived exceptions:

Pu-239 has T_e = 100 y. ALI = 300 Bq based on

H_W = 20 mSv in next 50 years.

1 DAC for 2000 hours = 1 ALI = 20 mSv

1 DAC-h = 20/2000 mSv = 10 μSv

1 DAC = committed dose rate of 10 μSv/h

TRITIUM

^{3}H or H-3 or T

$T_{½}$ = 12.3 y

Beta only, E_{max} = 18 kEv

need 70 kEv to penetrate dead skin

so internal hazard only

Production: $^{1}_{0}n + ^{2}_{1}H \rightarrow ^{3}_{1}H + \gamma$

Build-up: Fig.8.2, p.232

2.1E12 Bq/kg in mod

4.6E10 Bq/kg in PHT

H-3 conc. in air vs dose rate, Fig.8.3, p.324

TDO behaves like water vapour

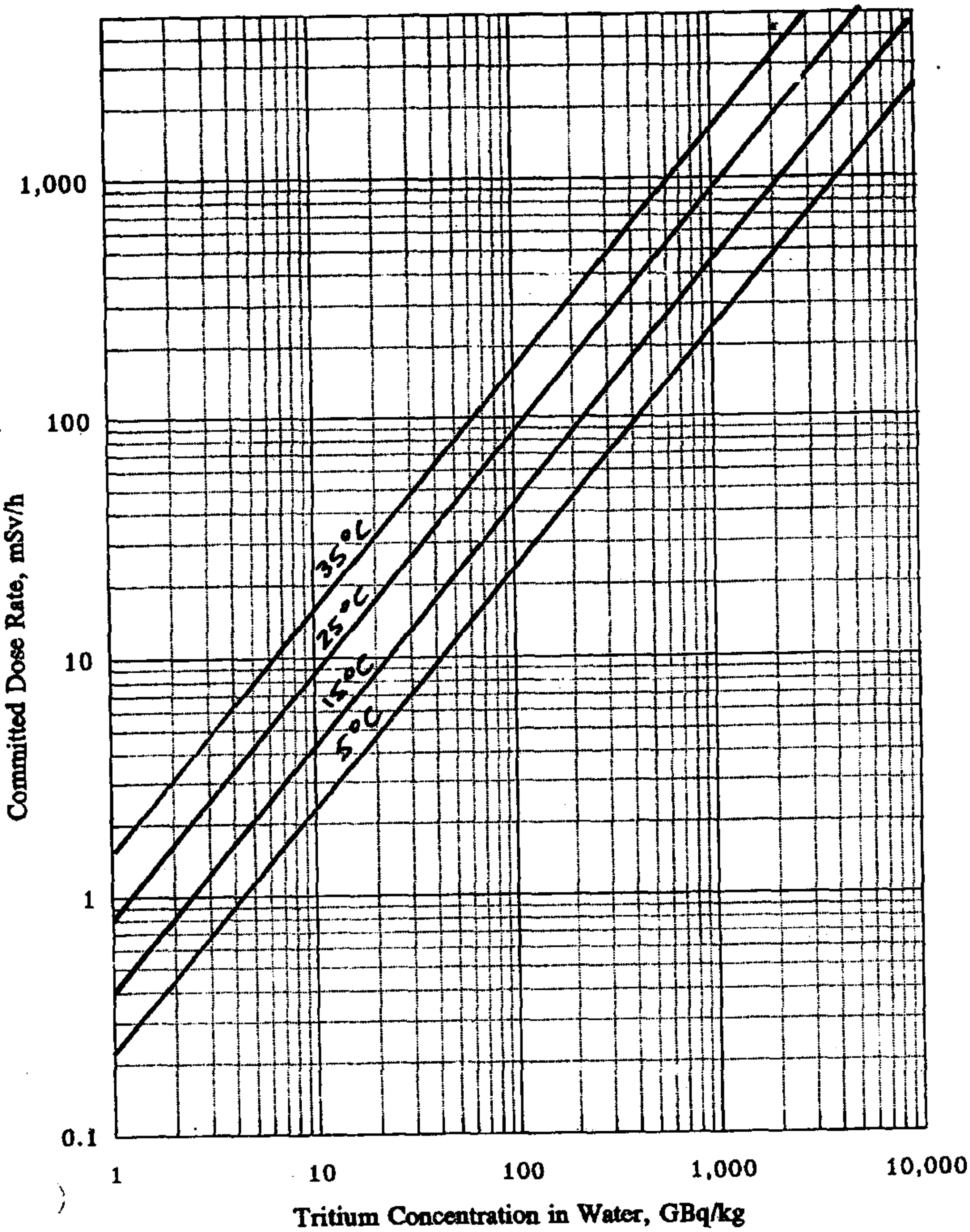


Fig. 8.3. Committed Dose Rate from Tritium in Air Saturated with Water Vapour

TRITIUM BEHAVIOUR IN THE BODY

Inhalation

Absorption through skin

Distributed among all body fluids (42L in 70 kg man)

63 kg of soft tissue, all exposed

3 L of water turnover per day (2 L in fluids, 1 L in food)
$\gamma = 3/42\ d^{-1}$, so $T_{1/2} = 10$ d
10 d is average, depends on fluid turnover

ALI = 1E9 Bq

DAC = ALI/(2400 x 1.5 m^3) = 3E5 Bq/m^3

1 DAC = 10 μSv/h

Urine samples: conc = max after 2 h

DOSE FROM TRITIUM

How many Bq of H-3 maintained in the body will give 20 mSv/y?

mean energy = 5.7 keV
target tissue = 63 kg
1 keV = 1.6E-16 J

Ans: 44E6 Bq

44E6 Bq/42 L of body fluids = 1.05 MBq/L

1% of H-3 is organically bound with $T_{1/2}$ = 100 d,
like 10% with $T_{1/2}$ = 10 d,
this is not seen in samples;
so we effectively see only 90% of the H-3,
therefore 0.95 MBq/L = MPBB

MPBB = that conc. which, if maintained, gives annual dose limit = 20 mSv/365 d = 55 uSv/d

Dose = (S1 + S2)/2 MBq/L x (55 uSv/d)/(0.95 MBq/L) x n days

see Figs. 8.4, 8.5

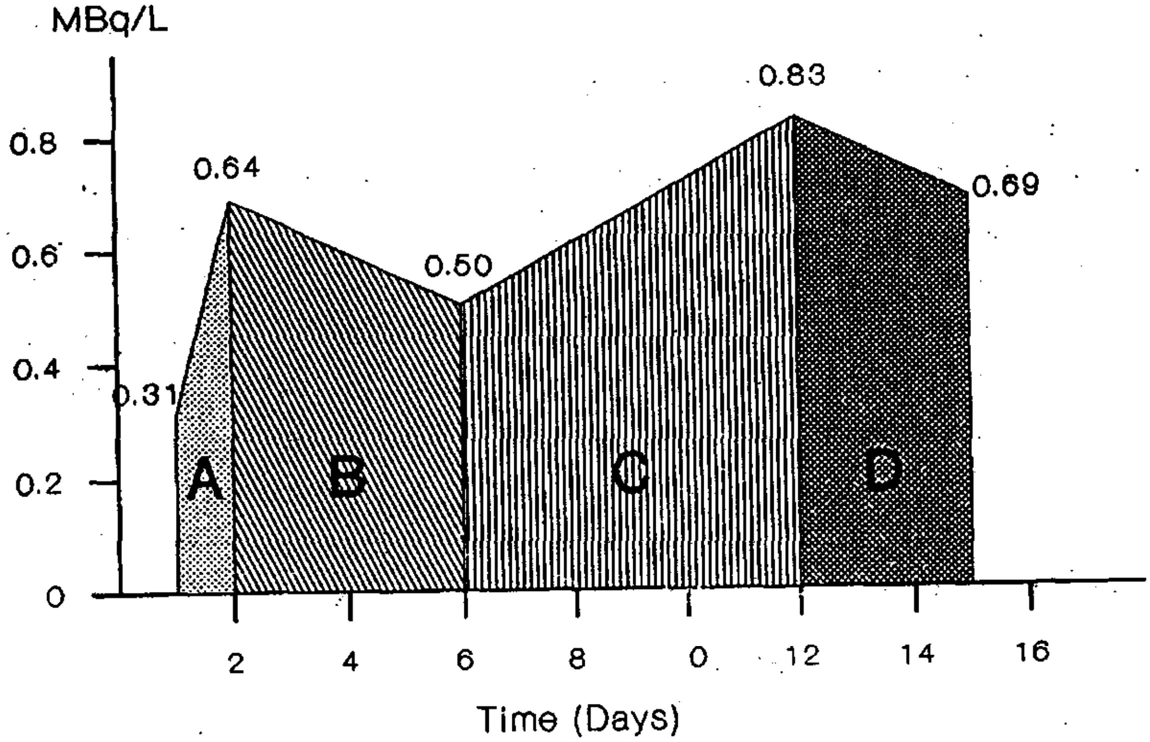


Fig. 8.4. Bioassay Data

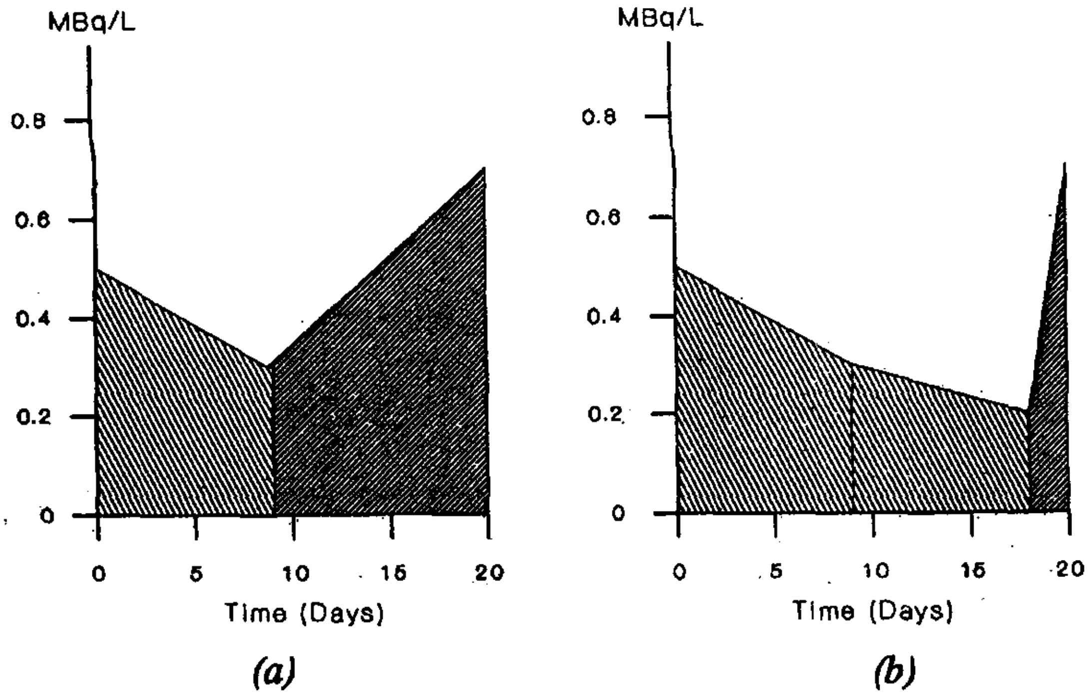


Fig. 8.5. Give a Sample Before and After Planned Exposures

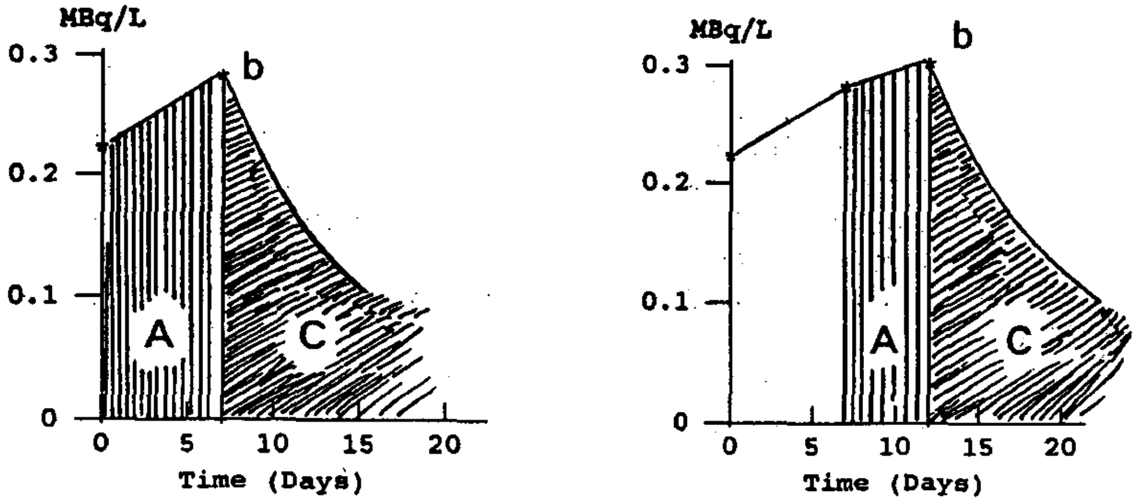
DOSE COMMITMENT

0.95 MBq/L gives 55 uSv/d

Calculate Infinity Dose H_∞ for $T_{1/2}$ = 10 d
Ans: 0.8 mSv
see Figs. 8.6, 8.7

Consider pick-up of
a) 10 μSv/h x 80 h,
b) 800 μSv/h x 1 h,
is dose same?
is Bq/L same?

Bioassay Update Report
(Fig.8.8 p.336; 10.5 p.466)



area A	= 0.10 mSv
point b	= 0.28 MBq/L
area c	= 0.24 mSv

area A	= 0.08 mSv
point b	= 0.30 MBq/L
area c	= 0.25 mSv

Fig. 8.8. Bioassy Update Calculations

PROTECTION

Before: Air-Supplied Plastic Suits

Air-Supplied Respirators

After: Increase Fluid Intake

Dialysis

PROBLEM SYSTEMS

Moderator

PHT

Other D_2O Systems

RADIOIODINE

	I-131	I-133	I-135
Radiation Emitted	β, γ	β, γ	β, γ
Radioactive Half-Life	8.0 d	21 h	6.6 h
Effective Half-Life	7.5 d	21 h	6.6 h
DAC (Bq/m^3)	4E2	3E3	2E4

Source: Defect fuel in PHT

PHT system leakage (I enters air, attaches to dust)

- **Fuelling Machine Vaults**
- **Fuelling Machine Maintenance Areas**
- **Fuel Storage Bays**
- **PHT Sample Stations**

thyroid uptake = 30% of intake

$T_{1/2}$ = 7.5 d for I-131

Dose Commitment; Respirators

Dose Measurement

KI Pills (130 mg KI) for H_T > 0.5 mSv

PARTICULATES

Fission Products, Activation Products deposited on dust on surface or in air. Inhaled: collects in lung.

Short-Lived and Long-Lived
(< 1 h several days)

Short Lived: external hazard; why?

Kr > Rb > Sr and Xe > Cs > Ba

Long-Lived: internal hazard

Ce-144	*I-131*	*Sr-89*	Mn-54
Ce-141	Ru-106	*Zn-65*	Cr-51
Ba-140/La-140	Ru-103	Co-60	*C-14*
Cs-137	Zr-95/Nb-95	Fe-59	
Cs-134	*Sr-90*		

all emit beta, gamma, except Sr-90, C-14

Transportable and non-transportable

DAC for LL based on Co-60: DAC = 200 Bq/m^3

Cs-134	800 Bq/m^3
Cs-137	800 Bq/m^3
Zr-95	1,000 Bq/m^3
Nb-95	4,000 Bq/m^3
C-14	20,000 Bq/m^3

PARTICULATE SOURCES AND LOCATIONS

Long-Lived:

fuel transfer systems

replacing mole sieves

sanding, machining, welding of pump impellers, seals

Short-Lived:

venting of D_2O tanks

fuel transfer

C-14

beta only, max E = 156 keV, $T_{1/2}$ = 5730 y

O-17 + n = C-14 + α (mod, PHT)

N-14 + n = C-14 + p (air)

C-14 does not decay, Ar-41 ($T_{1/2}$ = 1.8 h) does

hard to detect

DAC = 20,000 Bq/m^3

BIOASSAY

URINE ANALYSIS not useful because:

- only transportable detected
- fraction eliminated each day not well known

So use H-3 bioassay for screening, then WB count

FAECAL ANALYSIS generally not done:

- ingestion not a pathway
- only useful if energy emitted from lung is too low (low E gamma or beta)

WHOLE-BODY COUNTING

- measures body contents directly
- high sensitivity
- no good for beta-only emitters
- external contamination

ROUTINE BIOASSAY AT PLGS

Radionuclide	Bioassay Method	Frequency
Tritium	Urine analysis by liquid scintillation counting	Every 28 days, but daily for 1 mSv H_∞ , and weekly for 0.01 mSv H_∞
Radioiodine	a) High energy channel screening as part of routine H-3 program b) Self-serve thyroid monitor c) Whole-body counter	As for tritium Individual preference When required for accurate thyroid dose assignment
Gamma emitters (Co-60, Cs-137, Zr-95, etc.)	a) Whole-body counting b) High energy channel screening as part of routine H-3 program	Selected people in exposed groups, or as called for by b) As for tritium
Carbon-14	Medium energy channel screening as part of the routine H-3 program	As for tritium