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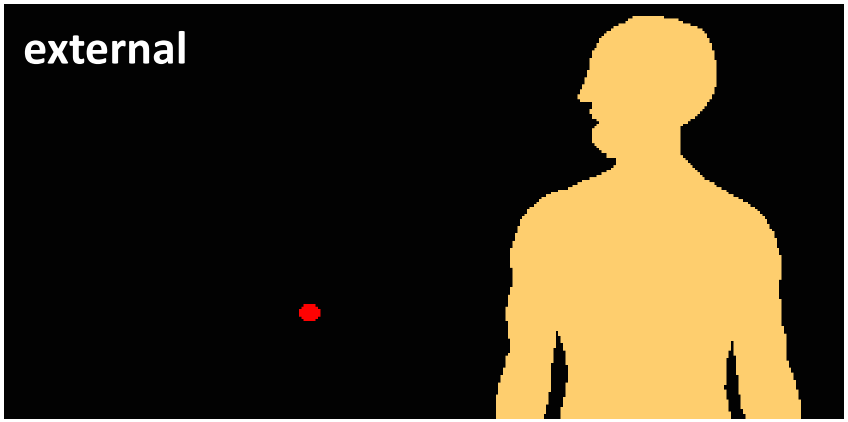
Chapter 4. Personal radiation protection monitoring

Parameters monitored



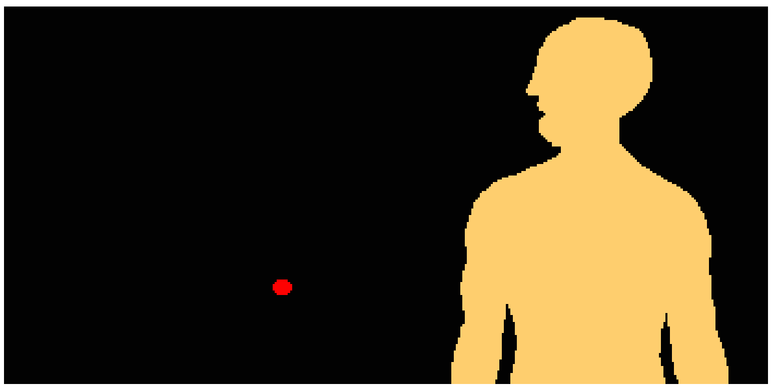
- Hp(10) & Hp(0.07)
- H_{ext}
  - similar to H(0.07) but measured at the hands or fingers

- E_{50}

Hp, H_{ext}, E_{50} **above the limits**: inquiry & estimation

limits

Hp, H_{ext}, E_{50} **below the limits**: directly defines E



Personal radiation protection monitoring

External irradiation

External measurement techniques

- Integrating dosimeters carried on the **chest** (badges)

- Integrating dosimeters worn near the **hands** (rings)

- Direct read or alarm dosimeters

Badge dosimeter

- Many numerical requirements
  - *see text (Ordinance on dosimetry)*
- Dosimetry services
  - should have official approval
  - dosimetric intercomparison once a year
- Monthly measurements
  - however, immediate reading is possible
- With a protective apron
  - **1 dosimeter**: should be worn **under** the apron
  - **2 dosimeters**: one **under** & one **above** the apron

$$H_p(10) = H_{p,underp}(10) + aH_{p,above}(10)$$

$$H_p(0.07) = H_{p,under}(0.07) + aH_{p,above}(0.07)$$

a=0.05 or 0.1

Estimation of the dose with an apron

- Exercise 1

1. Indicate the dose to record on the dosimetric document if two dosimeters (one under the apron and the other over it) give the following values:

$$H_{under} = 0{,}4 \text{ mSv} \quad ; \quad H_{over} = 2 \text{ mSv.}$$

Ring dosimeters

- Generally a thermoluminescent dosimeter
  - placed inside a ring
- Measures the dose received by the hands
  - supposed to estimate the highest dose
- Condition for wearing such a dosimeter
  - possible to receive H_s > _________mSv/y

Direct read dosimeters or alarm

- When risk is present or poorly understood
  - badge is combined with a direct-read instrument
- Currently only used in high dose rate situations

- **Advantages** of electronic dosimeters:
  - good precision
  - good exactitude
  - good detection limit
  - visual and audible alarms
  - dose and dose rate function
  - easy transfer of dosimetric information
  - good acceptability with users
    - more confidence values received immediately

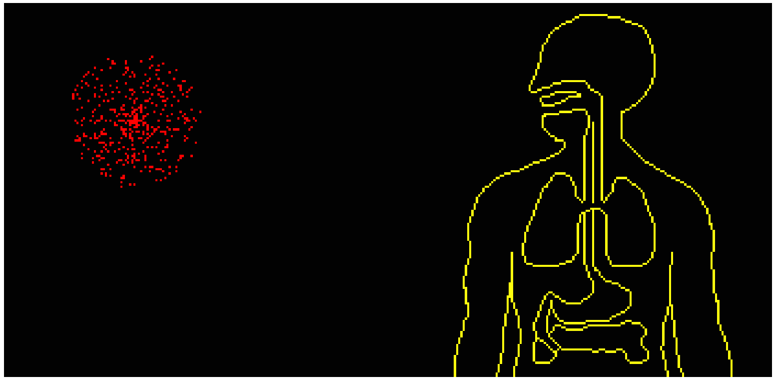
Direct read dosimeters or alarm

- **Drawbacks**
  - absence of national or international industrial standards
  - reticence of monitoring bodies toward these "new" dosimeters
  - relatively high price
  - underestimation of dose at high rates (some Gy/h)
    - dead time
    - problem in an accident situation
  - electromagnetic interference
  - difficulty in measuring surface dose
  - lack of dosimeter for extremities

Personal monitoring for **external** contamination

- With open sources
  - Monitoring of skin and clothing contamination
- Instrument shared by the co-workers
- If positive result (> CS)
  - cleaning
  - change clothing

  until activity is reduced below the tolerated threshold
- Doses are difficult to estimate and quite low
  - Not calculated, not taken into consideration



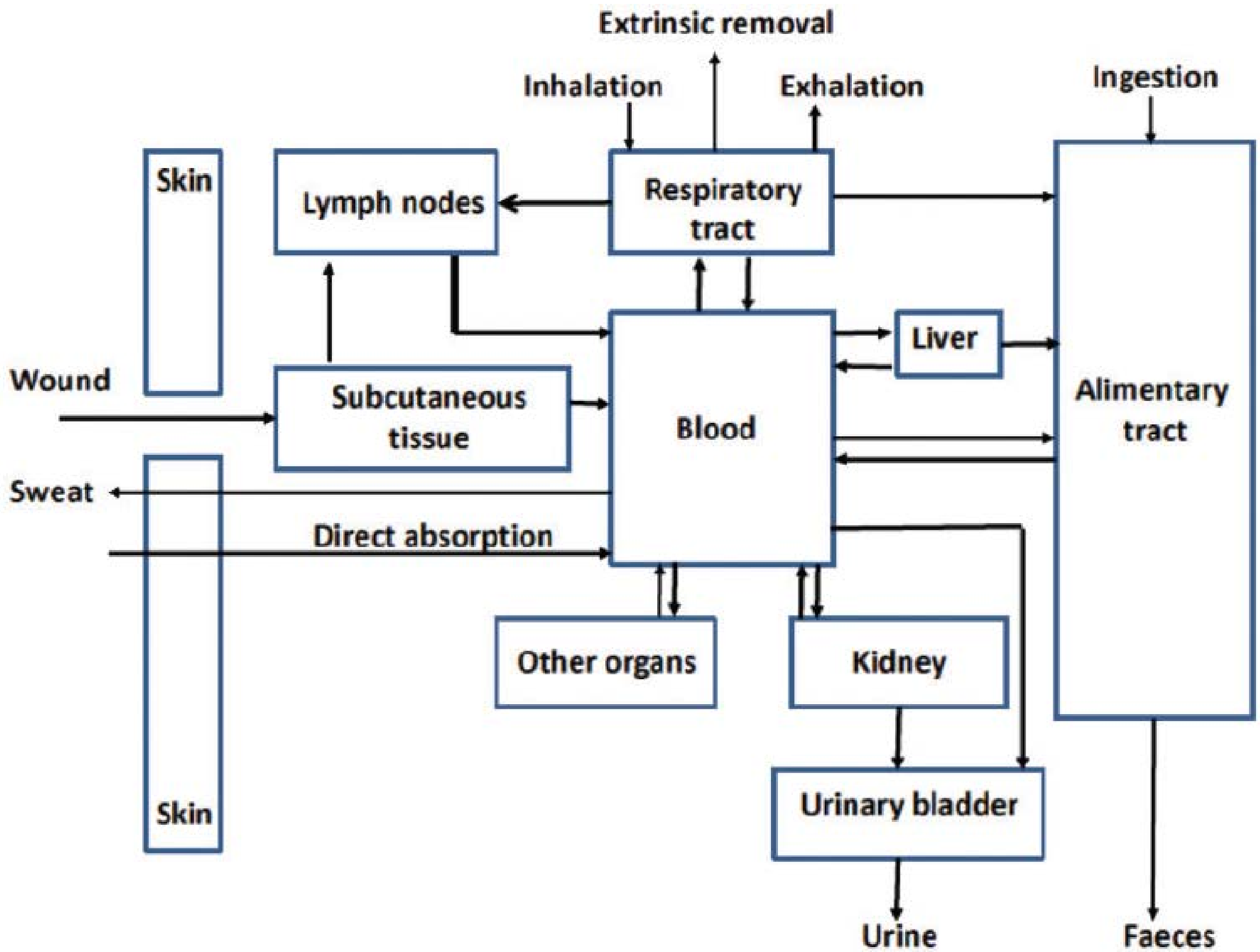
Personal radiation protection monitoring

Internal contamination

Personal monitoring for **internal** contamination

- Difficult to estimate the dose directly
  - It involves
    - physical parameters of the radionuclide
    - chemical characteristics
    - metabolization in the body
- In practice, incorporation is measured indirectly and compared to secondary limits
  - by determining the activity
    - in the entire organism
    - in an organ
  - by measuring activity in the feces or urine

Origin of **internal contamination**



Summary of the **main routes** of **intake**, **transfer**, and **excretion** of radionuclides in the body

Origin of internal contamination

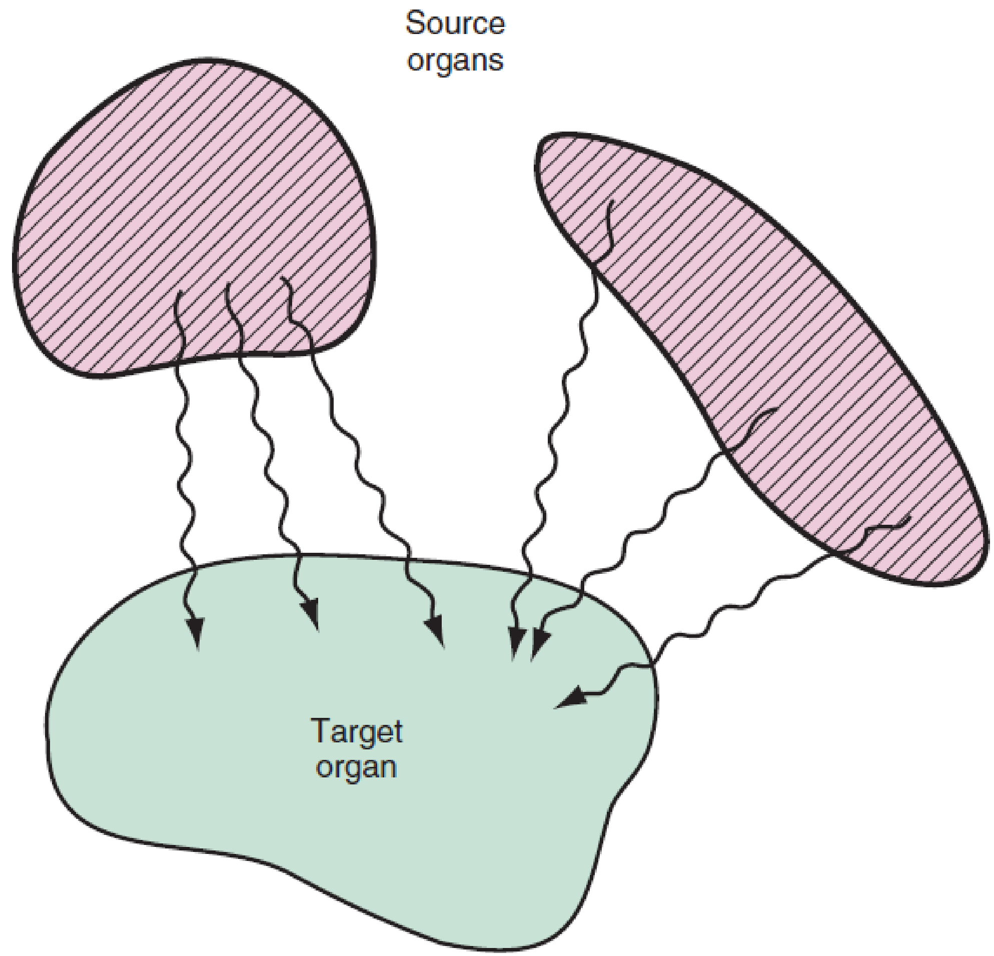


FIGURE 22-1 Absorbed dose delivered to a target organ from one or more source organs containing radioactivity is calculated by the absorbed fraction dosimetry method.

The irradiation can come from **other organs** or from **the organ itself**

Absorbed dose in an organ T (D_T)

Cumulated activity u_S ($U_S = I \cdot u_S$)
Number of decays in organ S
per unit of activity incorporated

Physiology
Biokinetic

Intake
(activity incorporated)

$$D_T = I \sum_S u_s S(S \rightarrow T)$$

Physics
Radiophysics & geometry

Specific Effective Energy Absorbed dose in organ *t* per decay in organ *s* [Sv (Bq s)$^{-1}$] (calculated by Monte Carlo simulation)

S factor *(specific effective energy)*

The energy emitted from an **organ *S*** and deposited in an **organ *T*** is computed by **Monte Carlo** simulation within a 3D phantom

$$S(S \rightarrow T) = \sum_R \frac{Y_R \varepsilon_R AF(S \rightarrow T)_R}{m_T}$$

- R : radiation R
- Y_R : yield of radiation R [(Bq s)$^{-1}$]
- ε_R : energy of radiation R [J]
- AF(T→S) : fraction of radiation R absorbed in T per decay in S
- m_T : mass of organ T [kg]

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Transport of energy from organ S to organ T is computed by **Monte Carlo simulation**

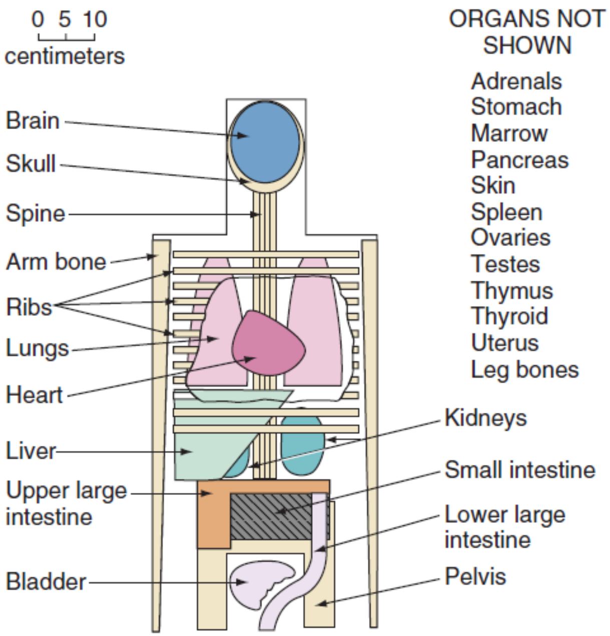
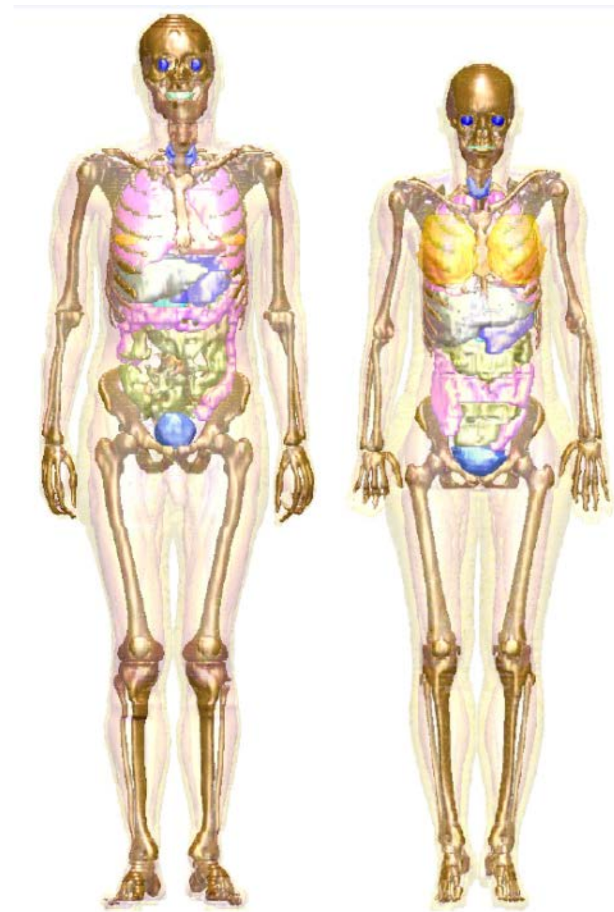


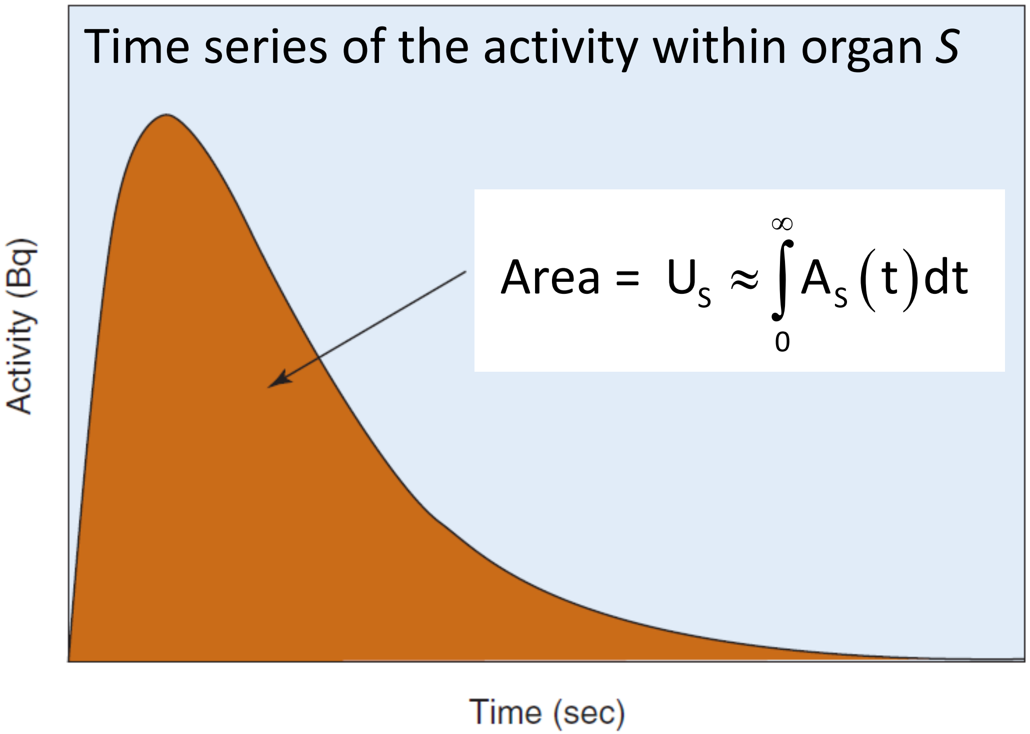
FIGURE 22-5 Representation of an "average man" used for MIRD dose calculations and tables. (*Adapted with permission from Snyder WS, Fisher HL Jr, Ford MR, Warner GG: Estimates of absorbed fractions for monoenergetic photon sources uniformly distributed in various organs of a heterogenous phantom.* J Nucl Med Suppl *3:9, 1969.*)

MIRD phantom



ICRP-110 voxel phantoms

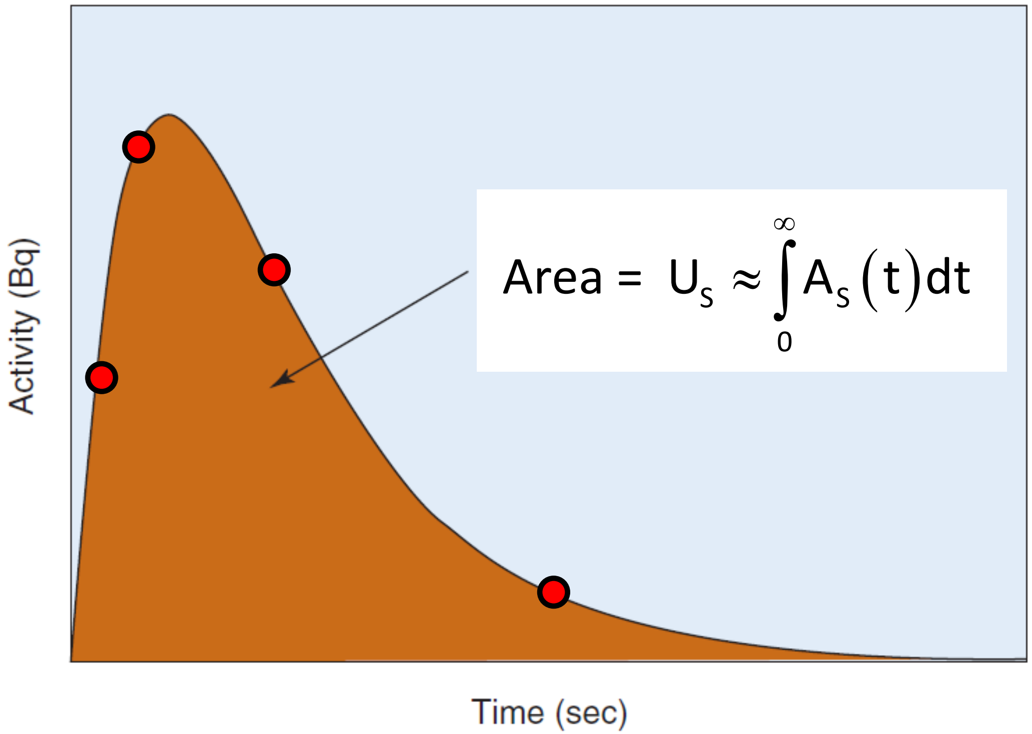
U_S: Cumulated activity

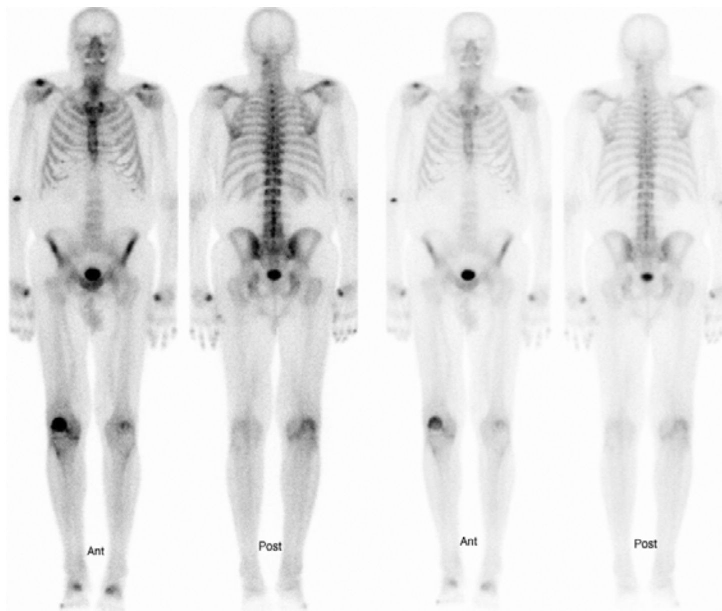


The **cumulated activity U_S** is the **total number of decays** within an organ S

Cherry, Sorenson, Phelps, Physics in Nuclear Medicine, Sauders Elsevir, 2012

U_S can be estimated **from direct measurements** in nuclear medicine





quantitative SPECT imaging performed **at different times** allows us to estimate U_S

Cherry, Sorenson, Phelps, Physics in Nuclear Medicine, Sauders Elsevir, 2012

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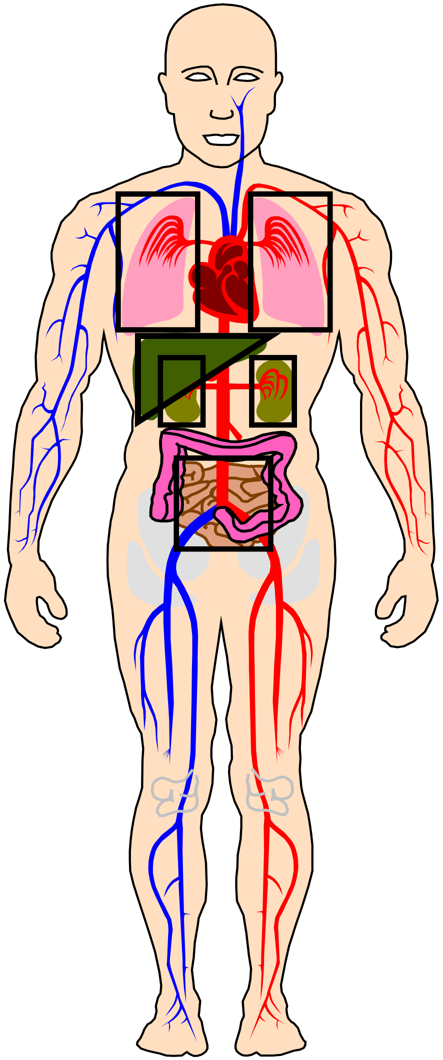
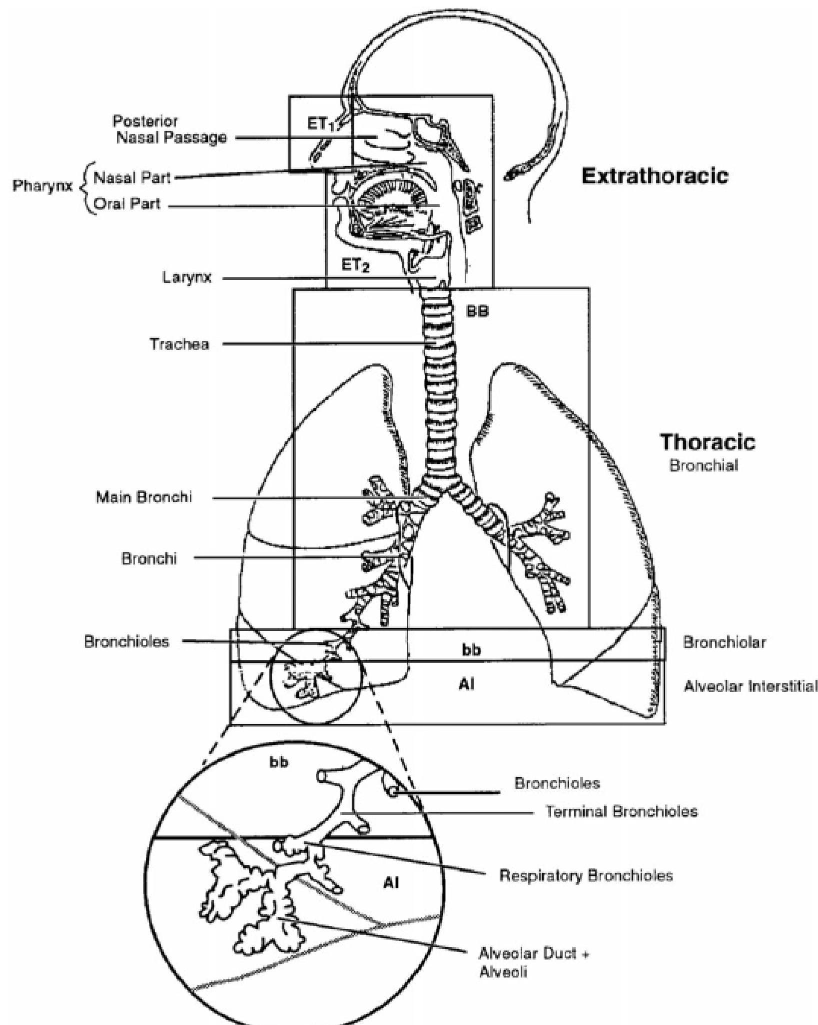
U_S can be **computed** with **compartmental biokinetic models**

- Organism divided in sub-systems
  - **Compartments**
  - (Instantaneously) homogenous
- **Continuous transfer** of the substance between these sub-systems
- **Flux** from one compartment to the other
  - **Proportional to the source**
  - Constant rate λ
    - Probability of transfer per unit of time



Example of a
compartmental biokinetic model



HRTM (human respiratory tract model) ICRP-66

Committed effective dose E_{50}

$$H_{50,T} = I \sum_S u_S \, S(S \rightarrow T)$$

equivalent dose to the organ T

$$S(S \rightarrow T) = \sum_R \frac{w_R Y_R \varepsilon_R AF(S \rightarrow T)_R}{m_T}$$

$$E_{50} = \sum_T w_T H_{50,T} = I \sum_T w_T \sum_S u_S \, S(S \rightarrow T)$$

committed effective dose

e_{inh} or e_{ing}

Simple computation in the Swiss federal **ordinance of radiation protection**

Based **on compartmental biokinetic models**, E_{50} can be easily computed in case of **ingestion** and **inhalation**

$$E_{50} = I_{inh} e_{inh} + I_{ing} e_{ing}$$

inhaled activity

ingested activity

Nuclide	Half-life	Type of decay/ radiation	e_{inh} Sv/Bq	e_{ing} Sv/Bq
1	2	3	4	5
Tc-97	2.6 E6 y	ε	1.6 E-10	8.3 E-11
Tc-97m	87 d	γ	2.7 E-09	6.6 E-10
Tc-98	4.2 E6 y	β^-, γ	6.1 E-09	2.3 E-09
Tc-99	2.13 E5 y	β^-	3.2 E-09	7.8 E-10
Tc-99m	6.02 h	γ	2.9 E-11	2.2 E-11
Tc-101	14.2 m	β^-, γ	2.1 E-11	1.9 E-11
Tc-104	18.2 m	β^-, γ	4.8 E-11	8.1 E-11

Known activity

- Exercise
  - A person ingests 300 kBq of Tc-99m
    - 1/1000 of a typical examination activity
  - What is the committed effective dose E_{50}

A person ingests **300 kBq of Tc-99m**

Nucléide	Période	Type de désintégra-tion/ de rayonnement	e_{inh} Sv/Bq	e_{ing} Sv/Bq
1	2	3	4	5
Tc-99	2.13 E5 a	β^-	3.2 E-09	7.8 E-10
Tc-99m	6.02 h	γ	2.9 E-11	2.2 E-11
Tc-101	14.2 m	β^-, γ	2.1 E-11	1.9 E-11
Tc-104	18.2 m	β^-, γ	4.8 E-11	8.1 E-11

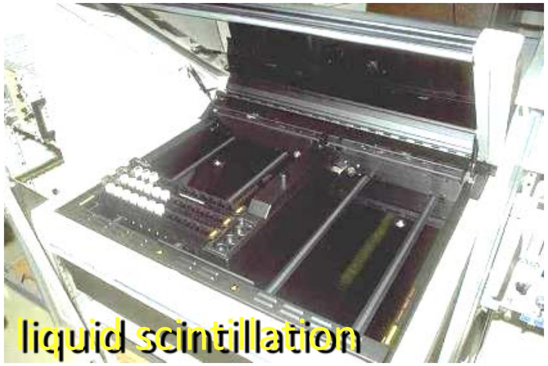
In vivo measurement

- gamma emitters

WBC ...

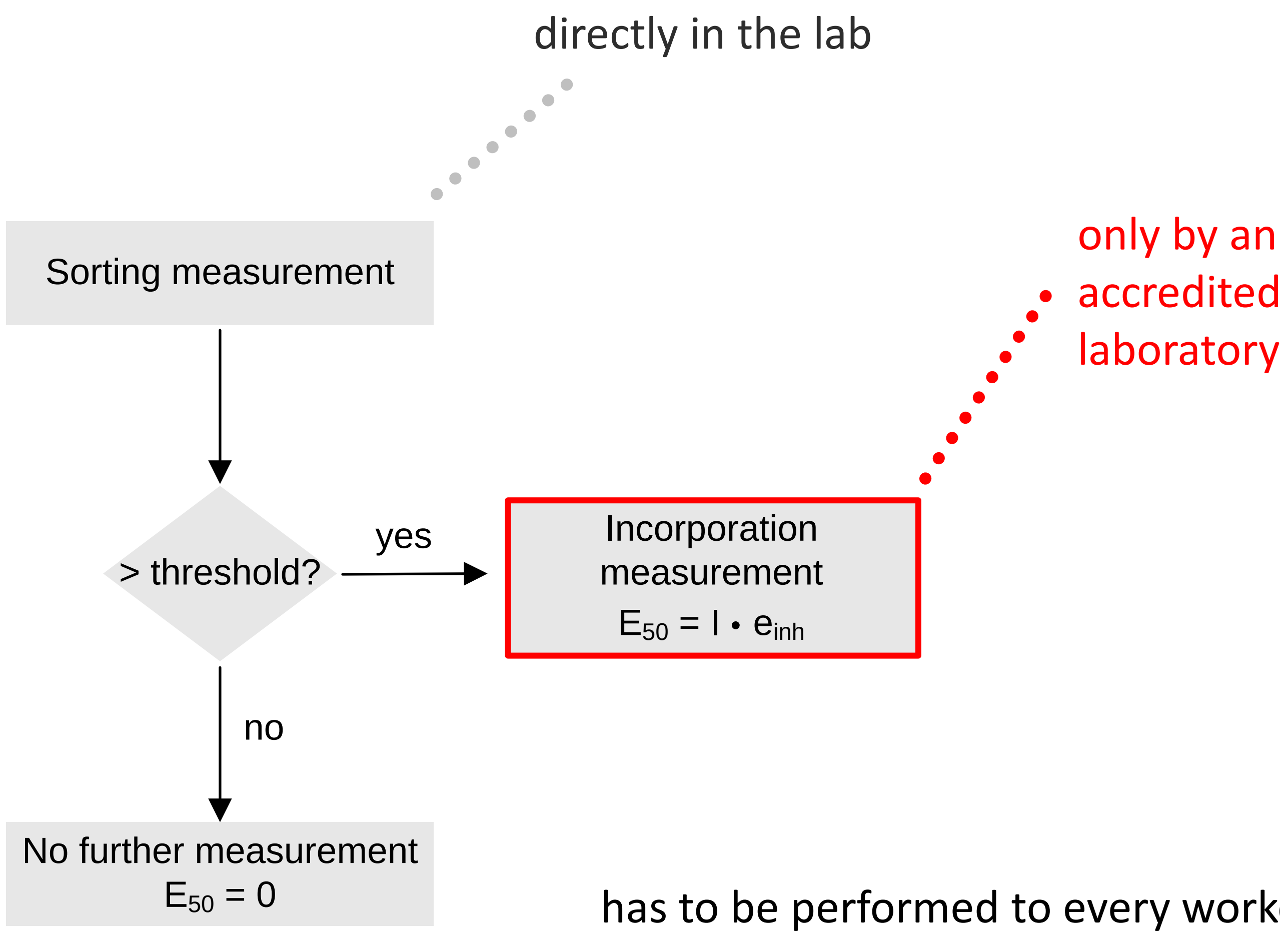
thyroid measurement

In vitro measurement




urine, blood, tears, feces

Measurement procedure



has to be performed to every worker that could potentially receive at least **0.1 mSv/year**

Measurement intervals

- Depends on
  - effective half-life of the radionuclide
  - detection limit of the instrument
- In practice
  - the incorporation occurred in the interval between 2 measurements
  - measurement interval defined as
    - no underestimation nor overestimation of a factor 3
    - exception
      - actinide incorporation
        - » detection limit too high

Swiss **ordinance on dosimetry**

27. I-131

27.1. Métabolisme

L'iode inhalé (classe d'absorption type F) est exhalé à 50 %. L'autre moitié atteint rapidement la circulation sanguine (taux de résorption $f_1 = 1$). De là environ 30 % est résorbé en 1 jour dans la glande thyroïde et 70 % est éliminé par voie urinaire. La période biologique dans la glande thyroïde est de 80 jours. La durée de séjour de l'iode-131 dans la thyroïde est ainsi déterminée par sa période physique de 8 jours.

27.2. Méthodes de mesure

Mesure de tri

Mesure directe de l'activité fixée dans la glande thyroïde avec un moniteur de contamination.

Seuil de mesure: 2000 Bq

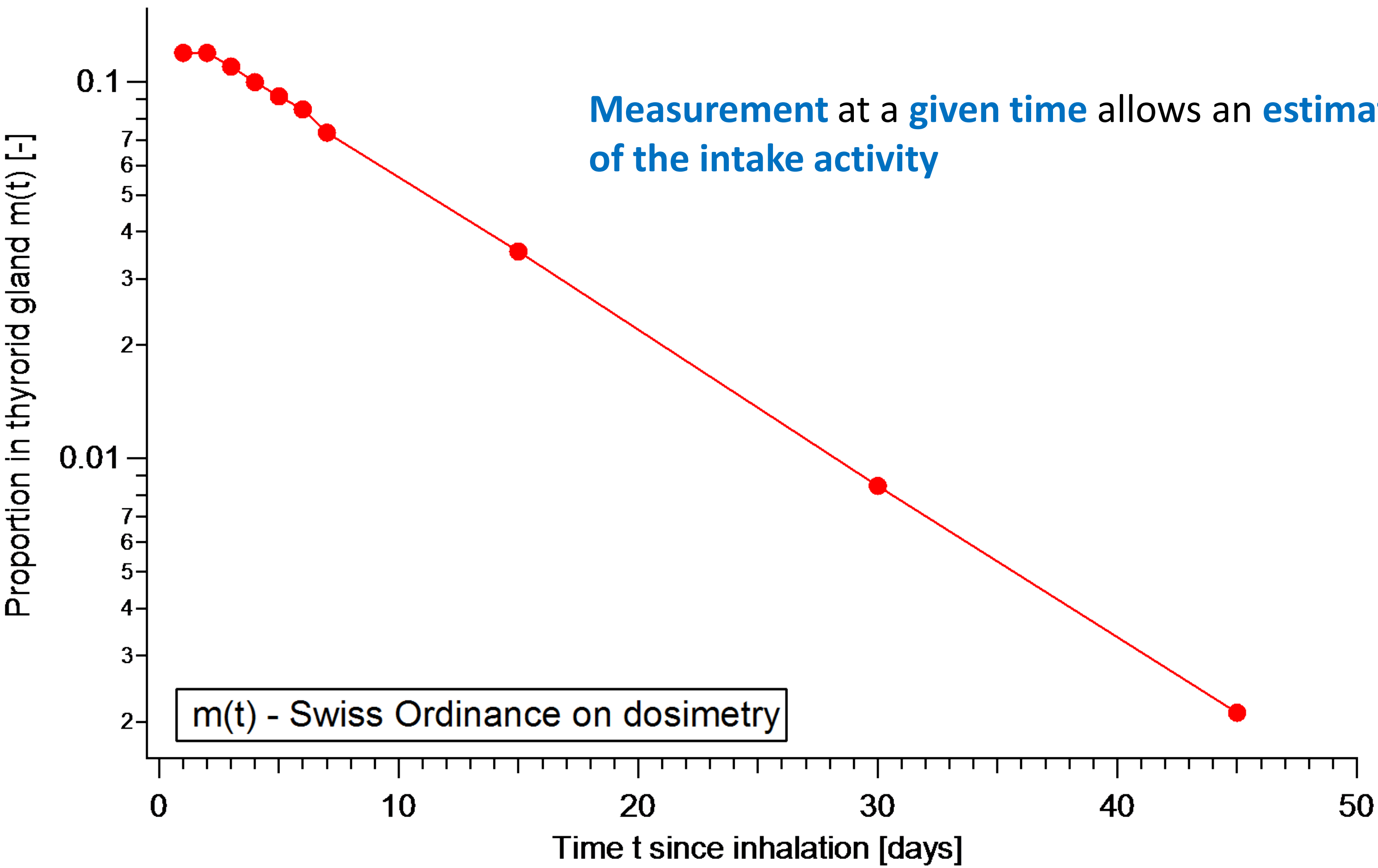
Mesure d'incorporation

Mesure à l'aide d'un moniteur thyroïdien de l'activité de I-131 M en Bq.

27.3. Intervalles de surveillance T et laps de temps t entre l'événement et la 1re mesure

T_{tri}:	7 jours	T_{mesure}:	30 jours	$t_{événement}$:	6–12 h

Iodine (^{131}I) in the thyroid



Measurement at a **given time** allows an **estimation of the intake activity**

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27.4. Interprétation sans tenir compte d'une incorporation antérieure

$$E_{50} = M \cdot \{e_{inh}/m(t)\}$$

E_{50}: Dose engagée durant 50 ans en Sv

M: Valeur de mesure en Bq

e_{inh}: Facteur de dose en Sv/Bq

m(t): Fraction de rétention

t: Laps de temps entre la mesure et l'incorporation en jours. Lorsque le moment de l'incorporation est inconnu, on pose t = T/2

Intervalle de surveillance = 30 jours

t [jour]	$e_{inh}/m(t)$ [Sv/Bq]
1	$0{,}092\times10^{-6}$
2	$0{,}092\times10^{-6}$
3	$0{,}10\times10^{-6}$
4	$0{,}11\times10^{-6}$
5	$0{,}12\times10^{-6}$
6	$0{,}13\times10^{-6}$
7	$0{,}15\times10^{-6}$
15	$0{,}31\times10^{-6}$
30	$1{,}3\times10^{-6}$
45	$5{,}2\times10^{-6}$

27.5. Correction pour une incorporation antérieure

Intervalle de surveillance T = 30 jours:

$$E_{50} = M \cdot 0{,}31 \cdot 10^{-6} - E_{50}^{a} \cdot 0{,}06$$

Incorporation of I-125

- Exercise 4
  - Calculate the committed effective dose received by an individual who has an Iodine-125 activity of 2 MBq in the thyroid gland during a quarterly exam

Incorporation of I-125

- Exercise
  - Calculate the committed effective dose received by an individual who has an Iodine-125 activity of 2 MBq in the thyroid gland during a quarterly exam

- Answer

E_{50} = M·{e_{inh}/m(t)}

E_{50}: 50-Jahre-Folgedosis in Sv
M: Messwert in Bq
e_{inh}: Dosisfaktor in Sv/Bq
m(t): Retentionsanteil
t: Tage zwischen Messung und Inkorporation. Bei unbekanntem Inkorporationszeitpunkt ist t = T/2

Überwachungsintervall T = 90 Tage

t [Tage]	e_{inh}/m(t) [Sv/Bq]
1	$0,56\times10^{-7}$
2	$0,52\times10^{-7}$
3	$0,52\times10^{-7}$
4	$0,56\times10^{-7}$
5	$0,56\times10^{-7}$
6	$0,56\times10^{-7}$
7	$0,56\times10^{-7}$
15	$0,66\times10^{-7}$
30	$0,90\times10^{-7}$
45	$1,2\times10^{-7}$
60	$1,6\times10^{-7}$
90	$2,6\times10^{-7}$
135	$6,1\times10^{-7}$

$E_{50} = 2\ 10^{6} \times 1.2\ 10^{-7}$
$= 0.24$ Sv = **240 mSv**

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Incorporation of tritium

- Exercise
  - A person is chronically contaminated with tritium
  - The last monthly control shows an activity concentration of 500 kBq/l
  - What is the committed effective dose?

Incorporation of tritium

- Exercise
  - A person is chronically contaminated with tritium
  - The last monthly control shows an activity concentration of 500 kBq/l
  - What is the committed effective dose?

- Answer

E_{50} = $C_u \cdot \{e_{inh}/m(t)\}$

E_{50}: 50-Jahre-Folgedosis in Sv

C_u: Messwert in Bq/l

e_{inh}: Dosisfaktor in Sv/Bq

m(t): Ausscheidungsanteil im Tagesurin (=1,4 l) in l^{-1}

t: Tage zwischen Messung und Inkorporation.
Bei unbekanntem Inkorporationszeitpunkt ist t = T/2

Überwachungsintervall T = 30 Tage

t [Tage]	$e_{inh}/m(t)$ [Sv·l/Bq]
1	$0{,}78\times10^{-9}$
2	$0{,}86\times10^{-9}$
3	$0{,}90\times10^{-9}$
4	$0{,}95\times10^{-9}$
5	$1{,}1\times10^{-9}$
6	$1{,}1\times10^{-9}$
7	$1{,}2\times10^{-9}$
15	$2{,}0\times10^{-9}$
30	$5{,}3\times10^{-9}$
45	13×10^{-9}

$E_{50} = 500\ 10^3 \times 1.4\ 10^{-9}$
$= 0.0007$ Sv = **0.7 mSv**

5. Interpretation für dauernde Inkorporation

Überwachungsintervall T = 30 Tage: $E_{50} = C_u \cdot 1{,}4 \cdot 10^{-9}$ (Sv pro Überwachungsintervall)

Monitoring program for tritium

- Exercise 2

2. Indicate a monitoring program for an individual working with an open source of Tritium.

Anthropogammametric measurement of Co-60

- Exercise 5
  - We measure an activity of 5 MBq of Cobalt-60 during an anthropogammametric exam. Estimate the dose if we say the intake occurred three months previously

Anthropogammametric measurement of Co-60

- Exercise
  - We measure an activity of 5 MBq of Cobalt-60 during an anthropogammametric exam. Estimate the dose if we say the intake occurred three months previously
- Answer

		t [jour]	$e_{inh}/m(t)$ [Sv/Bq]
E_{50} =	**$M \cdot \{e_{inh}/m(t)\}$**		
		1	$0{,}35 \times 10^{-7}$
E_{50}:	Dose engagée durant 50 ans en Sv	2	$0{,}68 \times 10^{-7}$
M:	Valeur de mesure en Bq	3	$1{,}2 \times 10^{-7}$
e_{inh}:	Facteur de dose en Sv/Bq	4	$1{,}7 \times 10^{-7}$
m(t):	Fraction de rétention	5	$2{,}1 \times 10^{-7}$
t:	Laps de temps entre la mesure et l'incorporation en jours. Lorsque le moment de l'incorporation est inconnu, on pose t = T/2	6	$2{,}3 \times 10^{-7}$
		7	$2{,}5 \times 10^{-7}$
		15	$2{,}8 \times 10^{-7}$
		30	$3{,}1 \times 10^{-7}$
		60	$3{,}8 \times 10^{-7}$
	Intervalle de surveillance T = 180 jours	90	$4{,}3 \times 10^{-7}$
		180	$5{,}3 \times 10^{-7}$
		270	$6{,}1 \times 10^{-7}$

5. Correction pour une incorporation antérieure

Intervalle de surveillance T = 180 jours:	$E_{50} = M \cdot 4{,}3 \cdot 10^{-7} - E_{50}^{a} \cdot 0{,}70$

$E_{50} = 5\ 10^{6} \times 4.3\ 10^{-7}$

= 2.15 Sv

Monitoring program for technetium

- Exercise 6

6. Imagine a monitoring measurement for the intake of Technetium-99m.

If the limit is exceeded

- A **specific determination** of the dose must be conducted, taking the specific situation into consideration
  - supposed moment of incorporation
  - individual's specific metabolism
  - specific incorporation path
  - chemical properties of the radioelement
- Has to be carried out **by an expert**
  - who will conduct an inquiry
  - and perform additional measurements

Medical monitoring

This has just been canceled

- At the beginning of the activity
- Periodically, according to a schedule defined by SUVA
  - usually every two years for situations involving a high risk of irradiation
  - when risk is low, "periodic" monitoring is advised
- Performed exams
  - complete blood work up
  - not expected to observe symptoms linked to radiations
    - (only deterministic effects could be seen)

Personal dosimetric document

- Each individual professionally exposed to radiation has a **personal dosimetric document**
  - The received doses are indicated
- This document
  - contains the doses received
  - is updated by the employer
  - is given to the individual when they leave their place of employment
  - is given to the new employer