Problem 1. The route of a ^{99m}Tc cow

A molybdenum/technetium generator is sent to a hospital by the manufacturer several days before Friday 28 April 2017. The (calculated) calibration time of this generator is 6.00 a.m. on Friday 28 April 2017; this is some time after the generator was sent by the manufacturer.

The generator is used for a few days at the hospital and is subsequently sent to a veterinary clinic on the morning of Monday 1 May 2017. The ^{99m}Tc is used there for a week for diagnoses in dogs and cats. On the morning of 8 May, the generator is sent from the veterinary clinic to a training institute and a week later the used generator is sent back to the hospital by the staff of the institute. The hospital returns the generator to the manufacturer. See also Table 1 for the calibration data and the more detailed dispatch schedule.

Table 1. Calibration data with dispatch schedule, type of transport label with the indicated activities and listed transport indices (TI).

Calibration data:
The activity ^{99}Mo is equal to 25.8 GBq on Friday 28 April, at 6.00 a.m.

Dispatch from:	Dispatch to:	Date:	Transport label:	Indicated ^{99}Mo act.:	TI
Manufacturer	Hospital	Unknown, before Friday 28 April	III Yellow	88.25 GBq	1.3
Hospital	Veterinary Clinic	Monday 1 May 10.00	II Yellow	13.2 GBq	0.5
Veterinary Clinic	Training Institute	Monday 8 May 10.00	II Yellow	2230 MBq	0.1
Training Institute	Hospital	Monday 15 May 10.00	I White	340 MBq	

Supporting data:

- Summary of the working of a ^{99m}Tc cow:
  The manufacturer of a molybdenum/technetium generator applied ^{99}Mo to the generator. Elution with physiological salt (the 'milking of the cow') causes ^{99m}Tc to dissolve in it. The result is a bottle with ^{99m}Tc dissolved in physiological salt, as used for diagnoses in nuclear medicine.
- **Appendix, pp. 3-5:** *Handboek Radionucliden*, [Radionuclides Handbook], A.S. Keverling-Buisman (2nd edition, 2007), pp. 120, 122 and 124, data of ^{99}Mo, ^{99}Tc and ^{99m}Tc respectively.

- The activity is placed in the middle of the Mo-Tc generator and may be considered as a point source.
- Enough lead has been applied around the activity to completely shield the radiation emitted by ^{99m}Tc.
- The transport packaging of the Mo-Tc generator is always the same standard type A packaging - a cardboard box of 39 cm × 39 cm × 39 cm.
- The Mo-Tc generator is placed in the middle of the box in such a way that the activity is positioned exactly in the centre of the package.

Question 1.1a

When (day and time) was the generator dispatched by the manufacturer according to the information on the transport label?

Question 1.1b

Calculate the transmission of the total package of the generator based on the information entered on the label by the manufacturer.

The generator will be returned to the hospital from the training institute in the original package on Monday 15 May. At the training institute, only the figures indicated by the manufacturer are used to calculate the ambient dose equivalent rate of the generator.

Question 1.2

Estimate the highest ambient dose equivalent rate at a distance of 1 metre from the packaged generator for Monday 15 May 2017 and also determine the TI for the same date.

Around 100 bone scans of dogs, as well as other types of scans, are made each year at the veterinary clinic. One of the assumptions in the risk analysis is the following anticipated unintended event:

A dog that was injected with 1500 MBq of ^{99m}Tc 3 hours earlier has just been let out in the special area designated for this purpose, but nevertheless urinates in the corridor leading to the scanner room. This results in 5% of the administered activity, now partially decayed, ending up on the floor in a puddle of around 10 ml.
This puddle is immediately cleaned up by means of absorption into cellulose with a gloved hand and the cellulose is then placed in a waste bag. This clean-up

takes 1 minute; during this time, the hands are at a distance of 1 cm from the activity.

Question 1.3

Based on the assumptions of the anticipated unintended event, calculate the ambient dose equivalent in the area of the hands of the person cleaning up the puddle. For the sake of simplicity, the puddle of 10 ml may be regarded as a point source.

The animals are not taken home until the day after the examination and therefore remain in the animal enclosures for quite some time after the activity is administered. These enclosures have a small outlet leading outside, where all excreta eventually end up in the soil.
These examinations have been conducted at the same location and in the same frequency for 40 years. The most important of these examinations - in number and with the highest ^{99m}Tc activity - are shown in Table 2.
The clinic is interested in determining the ^{99}Tc activity present in the ground at the animal enclosures.

Table 2. Overview of the most important examinations with ^{99m}Tc and the administered activity on an annual basis:

Examination type	Number of times per year	Activity per examination
Bone scans	100	$1.50 \cdot 10^9$ Bq
Thyroid scans	100	$1.50 \cdot 10^8$ Bq

Question 1.4

Calculate the activity of ^{99}Tc in the ground.
Assume that the animals excreted all of the administered ^{99m}Tc and ^{99}Tc during their stay, and that all of the formed ^{99}Tc remained in the ground at the location.

Problem 2. Contamination during ^{131}I therapy

To treat thyroid carcinoma, ^{131}I is administered to the patient in the form of sodium iodide after the removal of as much of the tumorous thyroid as possible. The dose to destroy the remaining tumour tissue (thyroid ablation) depends on the expected uptake of iodine in the remaining tumour tissue in the neck region.

Supporting data:

- **Appendix, p. 6:** Uptake of ^{131}I, including decay, in two organs after ^{131}I ingestion during the treatment of metastases, calculated using the HARAS model
- **Appendix, pp. 7-8:** *Handboek Radionucliden*, [Radionuclides Handbook], A.S. Keverling-Buisman (2nd edition, 2007), pp. 164-165, data of ^{131}I.

For a therapeutic thyroid ablation, 7400 MBq of ^{131}I is orally (via ingestion) administered to an adult patient. The patient's bladder is continuously emptied using a bladder catheter. The urine is collected in a plastic container with radiation shielding.

Question 2.1
Explain why continuously emptying the bladder can lead to a significant dose reduction for the patient. Use the uptake graph and decay diagram for this purpose.

The patient becomes aggressive 12 hours after administration, takes the collection container out of the shielding and hits the container, causing it to leak. The resulting contamination on the floor is cleaned up by a single employee. Measures are taken to prevent internal contamination. A measurement reveals that a large portion of the activity is still present in the container. The ambient dose equivalent rate $\dot{H}^*(10)$ of the unshielded container amounts to 22 μSv/h at a distance of 3.0 metres.

Question 2.2
Using the ambient dose equivalent rate, demonstrate that the activity of the remaining urine in the collection container is around 3 GBq. You can assume a point source geometry for the calculation.

The radiation expert takes a swipe sample from the nasal cavity and the oral cavity of the employee who cleaned up the contamination. An analysis reveals that the nasal sample and the oral sample are both positive. The radiation expert therefore ensures that a measurement is performed with an NaI detector a day after the incident to determine the activity of the ^{131}I in the body. The thyroid of the employee is measured for 1 minute, resulting in 567 pulses in the 365-keV photopeak. The background count rate in this photopeak amounts to 80 pulses per minute. The detection efficiency for the 365-keV photopeak in this set-up amounts to $1.0 \cdot 10^{-3}$ pulses per emitted photon.

Question 2.3

Estimate the activity of ^{131}I in the thyroid of the contaminated employee at the time of the measurement.

Question 2.4

Estimate the committed effective dose for the contaminated employee. Assume internal contamination resulting from the inhalation of sodium iodide and use the appendix, pp. 7-8, concerning the ^{131}I data.

Problem 3. Release of absolute filters

A company has a facility that can be used to produce specific radionuclides. One of these radionuclides is ^{99}Mo. During the production of this nuclide, radioactivity could be released into the air. Absolute filters are used to ensure that as little radioactivity as possible is released into the environment. These filters are placed in the outgoing air ventilation duct. After a certain period of time, these absolute filters are replaced with new ones. The KEW licence of the company prescribes that used absolute filters must be formally cleared prior to being disposed of as waste, after the performance of a suitable measurement. For this purpose, a new set-up is being designed, in which the filters are placed under a Ge(Li) detector. The detector is placed directly above the centre of the filter. A ^{57}Co plate source with the same geometry as the absolute filter is used as a reference source.

Supporting data:

- **Appendix, pp. 9-10:** *Handboek Radionucliden*, [Radionuclides Handbook], A.S. Keverling Buisman (3rd edition, 2007), pp. 66-67, data of ^{57}Co.
- **Appendix, p. 3:** *Handboek Radionucliden*, [Radionuclides Handbook], A.S. Keverling Buisman (3rd edition, 2007), p. 120, data of ^{99}Mo.
- **Appendix, p. 5:** *Handboek Radionucliden*, [Radionuclides Handbook], A.S. Keverling Buisman (3rd edition, 2007), p. 124, data of ^{99m}Tc.
- The total mass of the absolute filter is 3200 grams.
- All measurements were performed on 1 December 2016 and lasted 30 minutes.
- The dead time is negligible.
- At the time of the measurement, ^{99m}Tc is in equilibrium with ^{99}Mo.
- The efficiency determined for the 136-keV photons of ^{57}Co may also be used as the efficiency for the 141-keV photons from ^{99}Mo/^{99m}Tc.

Table 1. Results of a reference measurement (N_g is the gross number of counts, N_b is the number of counts during the background measurement).

Nuclide	Energy (keV)	Activity (kBq) on 1/4/2015	N_g on 1/12/2016	N_b on 1/12/2016
^{57}Co	136	469	$59.2 \cdot 10^3$	$50.7 \cdot 10^3$

Table 2. Results of a measurement of an absolute filter (N_g is the gross number of counts, N_b is the number of counts during the background measurement).

Nuclide	Energy (keV)	N_g on 1/12/2016	N_b on 1/12/2016
^{99}Mo/^{99m}Tc	141	$331.3 \cdot 10^3$	$50.9 \cdot 10^3$

Question 3.1

Demonstrate that the efficiency of the set-up for ^{57}Co energy of 136 keV is equal to $4.5 \cdot 10^{-4}$ counts per photon.

Question 3.2

^{99}Mo and ^{99m}Tc both emit photons with an energy of 141 keV. Verify that the yield of these photons is equal to 0.828 photons per desintegration ^{99}Mo, if the activities of the two nuclides are in equilibrium.

To ensure the success of this measurement, the clearance levels must be measurable and therefore higher than the minimum detectable activity (MDA) and minimal detectable activity concentration (MDC). The criterion for both the MDA and the MDC is that it must lead to an increase in the count rate of more than three times the standard deviation of the background (3σ).

Question 3.3

Demonstrate that both the MDA and the MDC for ^{99}Mo are smaller than the clearance levels.

Question 3.4a

Using the measurement of the absolute filter (Table 2), determine the maximum amount of the ^{99}Mo activity present in the absolute filter, including the 95% confidence interval (2σ) of that activity.

Question 3.4b

Determine whether this absolute filter can be cleared. Also take into account the ^{99m}Tc that has been formed in equilibrium with the activity of ^{99}Mo. Assume that no other radionuclides have been found besides ^{99}Mo/^{99m}Tc.

Question 4. Lecture bottle

A 'lecture bottle' is a miniature gas cylinder. In the radionuclide laboratory of a university, a teacher is going to use a steel lecture bottle filled with ^{14}C-labelled carbon dioxide in one of the fume cupboards. The responsible radiation expert performs a risk analysis in advance and initially assumes that the bremsstrahlung produced when the β-particles originating from the decay of ^{14}C enter the wall of the gas bottle can be disregarded. After the arrival of the lecture bottle, he performs a measurement to be certain. On the exterior of the gas bottle, an ambient dose equivalent rate $\dot{H}^*(10) = 0.17$ μSv h^{-1} is measured with a background of 0.06 μSv h^{-1}. He wants to verify by means of a calculation whether this measurement value could have been anticipated.

Figure 1. Lecture bottle

Supporting data:

- According to the label, the lecture bottle contains an activity of 480 MBq ^{14}C.
- The lecture bottle has a length of 18 cm, an outer diameter of 3.2 cm and a wall thickness of 3.0 mm.
- The surface area of the side wall of a cylinder is $S = 2\pi \times r \times l$, whereby r is the distance from the axis to the exterior of the cylinder and l is the length of the cylinder.
- In this assignment, the properties of iron may be used for steel.
- The density of iron is $\rho_{iron} = 7.9$ g·cm^{-3}.
- The atomic number of iron is $Z = 26$.

- The fraction of the β-energy that is converted to Bremsstrahlung is approximately equal to $g=2\cdot10^{-4}\ Z\ E_{\beta,max}$
- **Appendix, pp. 11-12:** *Handboek Radionucliden*, [Radionuclides Handbook], A.S. Keverling Buisman (2nd edition, 2007), pp. 24-25: data of ^{14}C.
- **Appendix, p. 13:** Interaction coefficients for photons in iron (derived from *Inleiding tot de Stralingshygiëne* [Introduction to Radiation Protection], A.J.J. Bos et al, 2nd edition, 2007, p. 384).
- The dose build-up factor may be equated to B = 1 in this problem.
- **Appendix, p. 13:** Dose conversion coefficients for external exposure to photons (derived from *Inleiding tot de Stralingshygiëne* [Introduction to Radiation Protection], A.J.J. Bos et al, 2nd edition, 2007, p. 386).
- **Figure 2**: Transmission through iron of bremsstrahlung produced by β-particles of ^{14}C; Radioisotopes 57 (2008) 605-616.

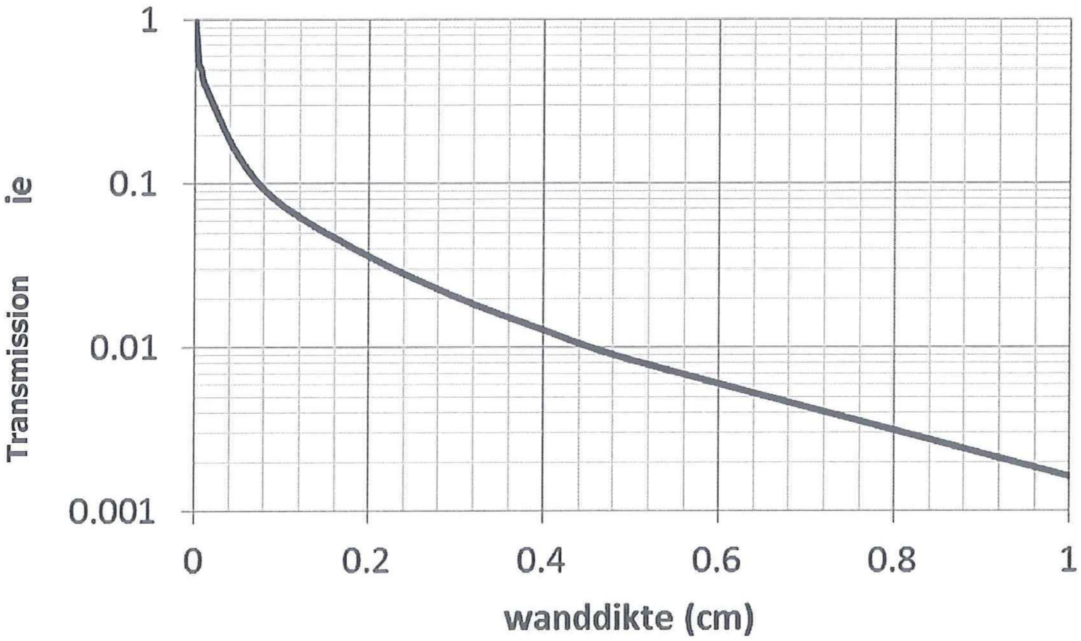

Figure 2. Transmission through iron of bremsstrahlung produced by β - particles of ^{14}C; Radioisotopes 57 (2008) 605-616.

Question 4.1

Demonstrate that all β-particles originating from the decay of ^{14}C are stopped in the wall of the gas bottle.

To make the problem manageable, the expert will make a calculation under the assumption that there is no ^{14}C in the cylinder, but instead a mono-energetic photon source with an energy equal to the effective photon energy E_{photon} to be determined in Question 4.2. This photon source is located on the axis in the centre of the cylinder and is homogeneously distributed across this axis; see Figure 3.

Question 4.2
Calculate the 'effective' value of μ/ρ of iron for the bremsstrahlung of ^{14}C, based on the transmission through iron. Using this value, determine the 'effective' photon energy E_{photon} (in other words, the energy corresponding to the calculated value of μ/ρ) of the bremsstrahlung.

If you are unable to obtain this answer, equate E_{photon} to the average β-energy in the remaining questions of this problem.

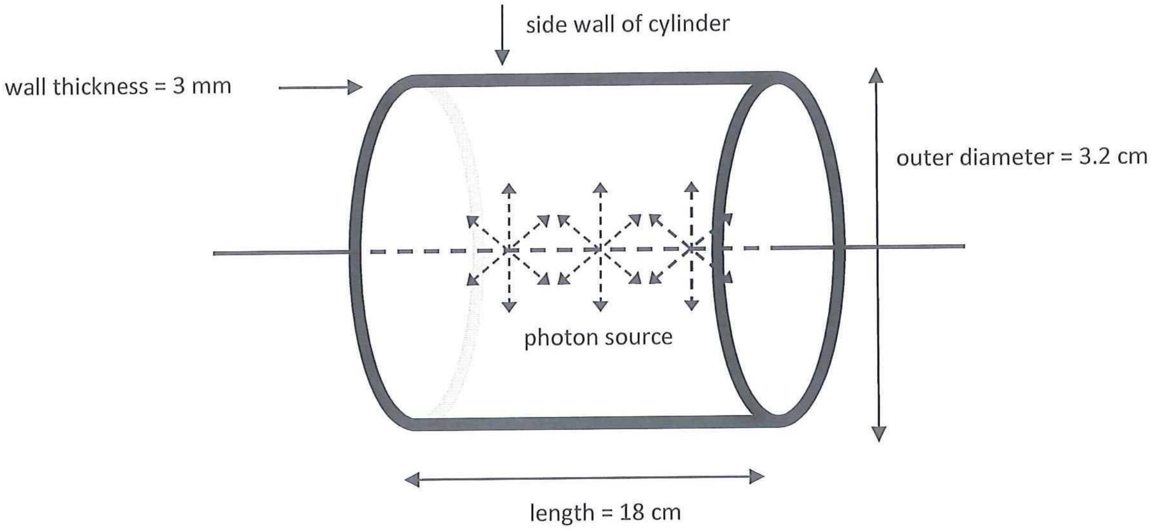

Figure 3. Outline of a segment of the gas bottle. The axis in the centre of the cylinder is considered to be the source of photons.

Question 4.3a
Calculate the total bremsstrahlung energy produced per unit of time (in $MeV \cdot s^{-1}$). For this calculation, use the fraction g of the β-energy emitted per unit of time.

He estimates the number of photons per unit of time by dividing the bremsstrahlung energy produced per unit of time by E_{photon}.

Question 4.3b
Calculate the average flux density or fluence rate φ (in photons·cm^{-2}·s^{-1}) that the imaginary linear photon source produces on the exterior of the gas bottle (see Figure 3). You do not need to take the ends of the gas bottle into account; you can assume that the photons exclusively come into contact with the inside of the side wall.

Question 4.4
Based on the answer to Question 4.3b, calculate the ambient dose equivalent rate $\dot{H}^*(10)$ (in µSv·h^{-1}) on the exterior of the gas bottle. If you were unable to obtain the answer to Question 3b, use 40 photons·cm^{-2} s^{-1}.

Embargo 15 May 2017

APPENDIX to the Examination Coordinating Radiation Protection Expert

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Nuclear Research and Consultancy Group	NRG
Delft University of Technology	TU Delft
Boerhaave CME/LUMC	BN/LUMC
University of Groningen	RUG
Radboudumc	RUMC
Eindhoven University of Technology	TU/e

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examination date: 15 May 2017
duration of examination: 13:30 - 16:30

Instructions:

- ☐ **If you use any data other than the data provided in this appendix, please state the source!**
- ☐ **This appendix consists of 13 numbered pages. Please check whether it is complete!**

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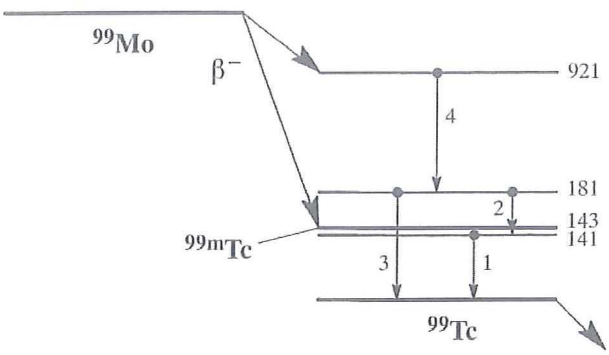
^{99}Mo Z = 42

Half-life and decay constant

$T_{1/2} = 65{,}94\ \mathrm{h} = 2{,}37\times10^{5}\ \mathrm{s}$ $\lambda = 2{,}92\times10^{-6}\ \mathrm{s}^{-1}$

Decay scheme (simplified)



Main emitted radiation

Straling	y (Bq·s)$^{-1}$	E (keV)
β^-	0,820	443 | 1214
β^-	0,166	133 | 436
γ_1	0,049	141
γ_2	0,012	41
γ_3	0,061	181
γ_4	0,122	740

Voor straling van dochters ^{99}Tc ($y = 0{,}124$) en ^{99m}Tc ($y = 0{,}876$): zie aldaar

Source constants

Air kerma rate	$k = 0{,}022$ μGy/h per MBq/m^2
Ambient dose equivalent rate	$h = 0{,}026$ μSv/h per MBq/m^2

Miscellaneous

Specific activity	$A_{\mathrm{sp}} = 1{,}77\times10^{16}$ Bq/g
Exemption levels	$C_{\mathrm{v}} = 10^2$ Bq/g en $A_{\mathrm{v}} = 10^6$ Bq
Skin contamination	$H_{\mathrm{huid}} = 4\times10^{-10}$ Sv/s per Bq/cm^2
Wound contamination / injection	$e(50) = 4{,}6\times10^{-10}$ Sv/Bq (incl. ^{99m}Tc)
Transport	$A_1 = 1$ TBq
	$A_2 = 0{,}6$ TBq

^{99}Tc

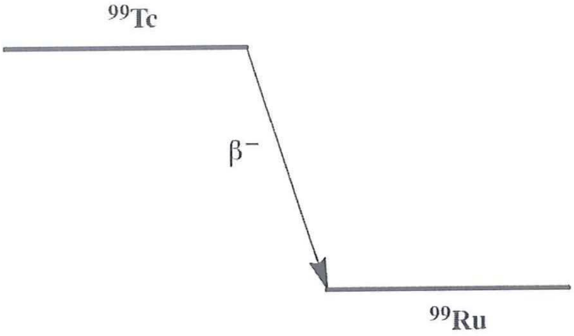
Z = 43

Half-life and decay constant

$T_{1/2} = 2{,}13\times10^{5}$ j $= 6{,}72\times10^{12}$ s

$\lambda = 1{,}03\times10^{-13}$ s^{-1}

Decay scheme (simplified)



Main emitted radiation

Straling	y (Bq·s)$^{-1}$	E (keV)
β^-	1,000	101 | 294

Miscellaneous

Specific activity	A_{sp}	$= 6{,}27\times10^{8}$ Bq/g
Exemption levels	C_v	$= 10^{4}$ Bq/g en $A_v = 10^{7}$ Bq
Skin contamination	H_{huid}	$= 3\times10^{-10}$ Sv/s per Bq/cm^2
Wound contamination / injection	$e(50)$	$= 1{,}8\times10^{-10}$ Sv/Bq
Transport	A_1	$= 40$ TBq
	A_2	$= 0{,}9$ TBq

Productie en toepassingen

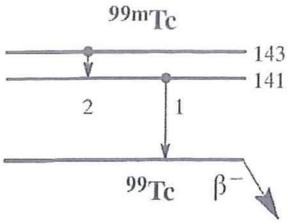
Het radionuclide ^{99}Tc is een splijtingsproduct.

^{99m}Tc Z = 43

Half-life and decay constant

$T_{1/2} = 6{,}006$ h = $2{,}17\times10^{4}$ s $\lambda = 3{,}21\times10^{-5}$ s^{-1}

Decay scheme (simplified)



Main emitted radiation

Straling	y (Bq·s)$^{-1}$	E (keV)
γ_1	0,889	141
ce M γ_2	0,914	2
ce N γ_2	0,076	2
K_α	0,062	18
LMX	0,102	2

Source constants

Air kerma rate	k = 0,018 µGy/h per MBq/m^2
Ambient dose equivalent rate	h = 0,023 µSv/h per MBq/m^2

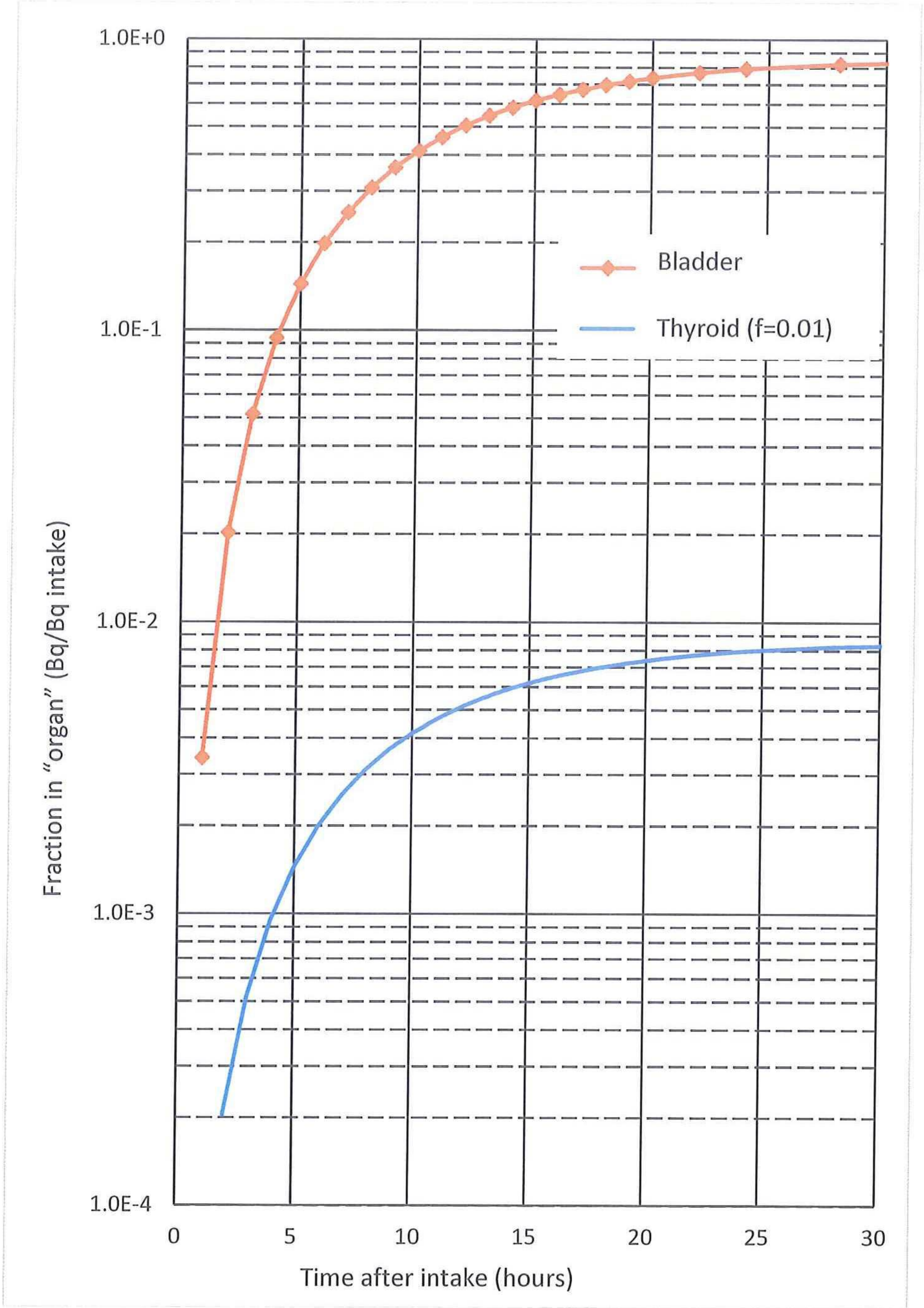
Miscellaneous

Specific activity	A_{sp} = $1{,}95\times10^{17}$ Bq/g
Exemption levels	C_v = 10^2 Bq/g en $A_v = 10^7$ Bq
Skin contamination	H_{huid} = 5×10^{-11} Sv/s per Bq/cm^2
Wound contamination / injection	$e(50)$ = $1{,}1\times10^{-11}$ Sv/Bq
Transport	A_1 = 10 TBq
	A_2 = 4 TBq

Productie en toepassingen

Het radionuclide ^{99m}Tc is de dochter van ^{99}Mo. Het wordt geproduceerd in een Mo/Tc-generator en op zeer grote schaal in de nucleaire geneeskunde gebruikt voor diagnostische doeleinden: voor afbeeldingen en functiestudies.

^{131}I uptake, including decay, in two organs after ^{131}I ingestion during the treatment of metastases, calculated using the HARAS model.

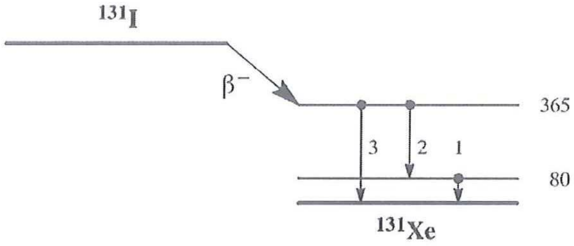


$^{131}\mathrm{I}$ Z = 53

Half-life and decay constant

$T_{1/2} = 8{,}021\ \mathrm{d} = 6{,}93\times10^{5}\ \mathrm{s}$ $\lambda = 1{,}00\times10^{-6}\ \mathrm{s}^{-1}$

Decay scheme (simplified)



Main emitted radiation

Straling	y (Bq·s)$^{-1}$	E (keV)
β^-	0,894	192 | 606
γ_1	0,026	80
ce K γ_1	0,036	46
γ_2	0,061	284
γ_3	0,812	365

Source constants

Air kerma rate	k = 0,052 μGy/h per MBq/m^2
Ambient dose equivalent rate	h = 0,066 μSv/h per MBq/m^2

Miscellaneous

Specific activity	A_{sp} = $4{,}60\times10^{15}$ Bq/g
Exemption levels	C_v = 10^2 Bq/g en $A_v = 10^6$ Bq
Skin contamination	H_{huid} = 4×10^{-10} Sv/s per Bq/cm^2
Wound contamination / injection	$e(50)$ = $2{,}2\times10^{-8}$ Sv/Bq
Transport	A_1 = 3 TBq
	A_2 = 0,7 TBq

Productie en toepassingen

Het radionuclide ^{131}I is een belangrijk splijtingsproduct. Het wordt veelvuldig toegepast in de diagnostische en therapeutische nucleaire geneeskunde.

N = 78 ^{131}I

Metabolic Model
For radiation protection purposes, it is assumed that iodine distributes itself from the blood as follows: 70% direct excretion and 30% to the thyroid. Iodine in the thyroid remains there with a biological half-life of 80 days and from there it is homogeneously distributed throughout the body in the form of organic iodine. It remains in other organs/tissue with a half-life of 12 days. A tenth of the organic iodine is immediately excreted in faeces, while the rest (90%) is returned to the transfer compartment. In this way, the biological half-life in the thyroid is effectively equal to 90 days.
N.B. This model does not apply to patients; see page 14.

Ingestion and lung clearance classes

Ingestie		
Alle verbindingen	$f_1 = 1$	
Inhalatie		
Damp (I_2)	$f_1 = 1$	Klasse SR-1
Damp (CH_3I)	$f_1 = 1$	Klasse SR-1 70% depositie
Overige verbindingen	$f_1 = 1$	Klasse F

Dose conversion coefficient and radiotoxicity equivalent for workers (w) and members of the public (b)

	Ingestie	Inhalatie	Inhalatie	Inhalatie	
	$f_1 = 1$	F	I_2	CH_3I	
$e(50)$(w)	$2{,}2\times10^{-8}$	$1{,}1\times10^{-8}$	$2{,}0\times10^{-8}$	$1{,}5\times10^{-8}$	Sv/Bq
A_{Re}(w)	$4{,}5\times10^{7}$	$9{,}1\times10^{7}$	$5{,}0\times10^{7}$	$6{,}7\times10^{7}$	Bq
$e(50)$(b)	$2{,}2\times10^{-8}$	$7{,}6\times10^{-9}$	$2{,}0\times10^{-8}$	$1{,}5\times10^{-8}$	Sv/Bq
A_{Re}(b)	$4{,}5\times10^{7}$	$1{,}3\times10^{8}$	$5{,}0\times10^{7}$	$6{,}7\times10^{7}$	Bq

Data for thyroid count (after single intake)

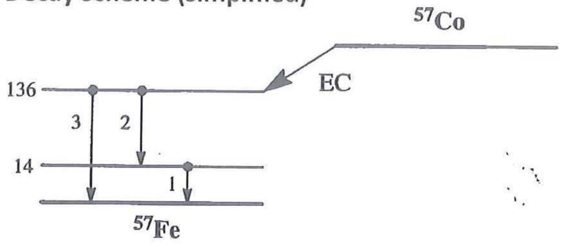
Time (d)	Activity in Thyroid (Bq per Bq intake)			
	$f_1 = 1$	F	I_2	CH_3I
0,25	$6{,}0\times10^{-2}$	$5{,}2\times10^{-2}$	$1{,}1\times10^{-1}$	$1{,}0\times10^{-1}$
1	$2{,}4\times10^{-1}$	$1{,}2\times10^{-1}$	$2{,}3\times10^{-1}$	$1{,}8\times10^{-1}$
2	$2{,}5\times10^{-1}$	$1{,}2\times10^{-1}$	$2{,}2\times10^{-1}$	$1{,}7\times10^{-1}$
3	$2{,}3\times10^{-1}$	$1{,}1\times10^{-1}$	$2{,}0\times10^{-1}$	$1{,}6\times10^{-1}$
5	$1{,}9\times10^{-1}$	$9{,}0\times10^{-2}$	$1{,}7\times10^{-1}$	$1{,}3\times10^{-1}$
7	$1{,}6\times10^{-1}$	$7{,}5\times10^{-2}$	$1{,}4\times10^{-1}$	$1{,}1\times10^{-1}$

^{57}Co Z = 27

Half-life and decay constant

$T_{1/2}$ = 271,84 d = $2,35\times10^{7}$ s $\qquad \lambda = 2,95\times10^{-8}\ \mathrm{s}^{-1}$

Decay scheme (simplified)



Main emitted radiation

Straling	y (Bq·s)$^{-1}$	E (keV)	Straling	y (Bq·s)$^{-1}$	E (keV)
γ_1	0,092	14	ce K γ_1	0,713	7
γ_2	0,856	122	ce K γ_2	0,018	115
γ_3	0,106	136	ce K γ_3	0,014	129
K_α	0,503	6			

Source constants

Air kerma rate	k = 0,022 μGy·m^2·MBq^{-1}·h^{-1}
Ambient dose equivalent rate	h = 0,023 μSv·m^2·MBq^{-1}·h^{-1}

Miscellaneous

Specific activity	A_{sp} = $3,12\times10^{17}$ Bq·kg^{-1}
Exemption levels	Gemiddeld (3) 10^2 Bq·g^{-1} en 10^6 Bq
Skin contamination	H_{huid} = 1×10^{-11} Sv·s^{-1}·Bq^{-1}·cm^2
Wound contamination / injection	$e(50)$ = $5,9\times10^{-10}$ Sv·Bq^{-1}
Transport	A_1 = 8 TBq A_2 = 8 TBq

Produktie en toepassingen

Het radionuclide ^{57}Co wordt geproduceerd met behulp van een cyclotron: protonen op ijzer. Het wordt toegepast in de geneeskunde (vitamine-B-stofwisseling, testbron voor gamma-camera, botdensitometrie). In de vaste-stoffysica vindt ^{57}Co een speciale toepassing, namelijk als Mössbauer-bron.

N = 30 ^{57}Co

Internal contamination

Metabolic model.

For radiation protection purposes, it is assumed that cobalt distributes itself from the blood as follows: 50% direct excretion, 5% to the liver and 45% to the rest of the body. Biological half-life: 0.5 days.

The biological half-lives for the organs are:

Fraction	$T_{1/2}$
0,6	6 d
0,2	60 d
0,2	800 d

Ingestion and lung clearance classes

Ingestie

Oxide, hydroxide en anorganisch	$f_1 = 0{,}05$
Overige verbindingen	$f_1 = 0{,}1$

Inhalatie

Oxide, hydroxide, halogenide, nitraat	$f_1 = 0{,}05$	Klasse S
Overige	$f_1 = 0{,}1$	Klasse M

Dose conversion coefficient and radiotoxicity equivalent for workers (w) and members of the public (b)

	Ingestie	Ingestie	Inhalatie	Inhalatie
	$f_1 = 0{,}1$	$f_1 = 0{,}05$	M	S
e(50) (Sv/Bq)	$2{,}1\times10^{-10}$	$1{,}9\times10^{-10}$	$3{,}9\times10^{-10}$	$6{,}0\times10^{-10}$
RE (Bq)	5×10^{9}			2×10^{9}

Data for total body counting

Single intake

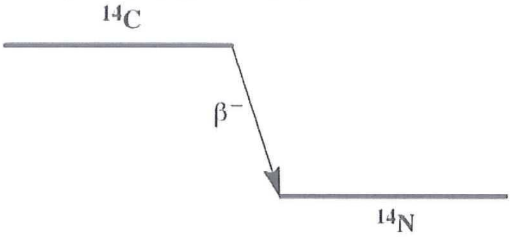
Time (d)	Total body activity (Bq per Bq intake)			
0,25	$9{,}7\times10^{-1}$	$9{,}8\times10^{-1}$	$7{,}4\times10^{-1}$	$7{,}4\times10^{-1}$
1	$6{,}8\times10^{-1}$	$7{,}1\times10^{-1}$	$4{,}8\times10^{-1}$	$4{,}9\times10^{-1}$
2	$3{,}7\times10^{-1}$	$3{,}3\times10^{-1}$	$2{,}5\times10^{-1}$	$2{,}5\times10^{-1}$
3	$2{,}2\times10^{-1}$	$1{,}5\times10^{-1}$	$1{,}4\times10^{-1}$	$1{,}4\times10^{-1}$
5	$1{,}3\times10^{-1}$	$3{,}7\times10^{-2}$	$8{,}2\times10^{-2}$	$7{,}8\times10^{-2}$
7	$1{,}0\times10^{-1}$	$1{,}9\times10^{-1}$	$7{,}0\times10^{-2}$	$6{,}6\times10^{-2}$
Continuous intake				
Bq/ $(\mathrm{Bq\cdot d^{-1}})$	3,5	13	8,4	13
$\mathrm{Sv\cdot j^{-1}\cdot Bq^{-1}}$	$8{,}7\times10^{-9}$	$1{,}9\times10^{-8}$	$1{,}7\times10^{-8}$	$1{,}8\times10^{-8}$

^{14}C Z = 6

Half-life and decay constant

$T_{1/2}$ = 5730 j = $1{,}81\times10^{11}$ s $\lambda = 3{,}83\times10^{-12}\ s^{-1}$

Decay scheme (simplified)



Main emitted radiation

Straling	y (Bq·s)$^{-1}$	E (keV)
β^-	1,000	49 | 156

Miscellaneous

Specific activity	A_{sp}	= $1{,}65\times10^{11}$ Bq/g	
Exemption levels	C_v	= 10^8 Bq/g	(CO)
		= 10^7 Bq/g	(CO_2)
		= 10^4 Bq/g	(overige)
	A_v	= 10^{11} Bq	(CO, CO_2)
		= 10^7 Bq	(overige)
Skin contamination	H_{huid}	= 5×10^{-11} Sv/s per Bq/cm^2	
Wound contamination / injection	$e(50)$	= $5{,}8\times10^{-10}$ Sv/Bq	
Transport	A_1	= 40 TBq	
	A_2	= 3 TBq	

Productie en toepassingen

Het radionuclide ^{14}C wordt gevormd in de buitenste lagen van de atmosfeer, voornamelijk door de (exotherme) reactie $^{14}N(n,p)^{14}C$. De concentratie van $^{14}CO_2$ in de biosfeer is hierdoor ongeveer 220 Bq/kg C. De stofwisseling van planten (CO_2 in en O_2 uit) maakt dat plantaardige stoffen dezelfde ^{14}C-concentratie bevatten als in de atmosfeer. Na de dood van de plant neemt de ^{14}C-concentratie af met de halveringstijd van 5730 jaar. Door meting van deze concentratie kan dus de ouderdom van plantaardige stoffen worden bepaald: de koolstofdateringsmethode. Door het verbranden van (zeer oude) fossiele brandstoffen neemt de ^{14}C-concentratie de laatste jaren geleidelijk af.
De mens bevat enig ^{14}C: de referentiemens is opgebouwd uit 16 kg koolstof en bevat

N = 8

^{14}C

zodoende 3500 Bq ^{14}C. Door bovengrondse kernproeven is sinds 1945 ongeveer 0,2 EBq in de atmosfeer terechtgekomen. Het radionuclide wordt verder gebruikt als merker van biologische verbindingen en als zeer stabiele lichtbron.

Metabolic model

Voor stralingshygiënische doeleinden wordt aangenomen dat koolstof zich na ingestie en inhalatie momentaan en homogeen over het lichaam verdeelt.
Er gelden verschillende biologische halveringstijden zoals aangegeven in onderstaande tabel.

Ingestion and lung clearance classes

		Biologische $T_{1/2}$
Ingestie		
Alle verbindingen	$f_1 = 1$	40 d
Inhalatie		
Organische aerosolen	M	40 d
Organische dampen	SR-2	40 d
CO	SR-1, 40% dep.	200 min
CO_2	SR-2	5 d (18%), 60 d (81%), 40 d (1%)

Dose conversion coefficient and radiotoxicity equivalent for workers (w) and members of the public (b)

	Ingestie	Inhalatie	Inhalatie	Inhalatie	Inhalatie	
	$f_1 = 1$	M	Damp	CO	CO_2	
$e(50)$	$5{,}8\times10^{-10}$	$2{,}0\times10^{-9}$	$5{,}8\times10^{-10}$	$8{,}0\times10^{-13}$	$6{,}2\times10^{-12}$	Sv/Bq
A_{Re}	$1{,}7\times10^{9}$	$5{,}0\times10^{8}$	$1{,}7\times10^{9}$	$1{,}3\times10^{12}$	$1{,}6\times10^{11}$	Bq

Data for urine analysis

After single intake

Time (d)	Urine excretion rate (Bq/d per Bq intake) with F_u=0.017				
1	$1{,}2\times10^{-4}$	$9{,}3\times10^{-6}$	$1{,}2\times10^{-4}$	$1{,}6\times10^{-2}$	$3{,}7\times10^{-4}$
2	$2{,}7\times10^{-4}$	$1{,}8\times10^{-5}$	$2{,}7\times10^{-4}$	$1{,}1\times10^{-4}$	$3{,}2\times10^{-4}$
3	$2{,}8\times10^{-4}$	$1{,}9\times10^{-5}$	$2{,}8\times10^{-4}$	$3{,}5\times10^{-7}$	$2{,}9\times10^{-4}$
5	$2{,}7\times10^{-4}$	$1{,}9\times10^{-5}$	$2{,}7\times10^{-4}$	–	$2{,}0\times10^{-4}$
7	$2{,}6\times10^{-4}$	$1{,}8\times10^{-5}$	$2{,}6\times10^{-4}$	–	$1{,}5\times10^{-4}$

Interaction coefficients for photons in iron
Inleiding tot de Stralingshygiëne [Introduction to Radiation Protection], (Bos et al., 2nd edition, 2007), page 384.

Photon energy (MeV)	μ/ρ ($cm^2\ g^{-1}$)	μ_{en}/ρ ($cm^2\ g^{-1}$)
0.02	25.7	22.1
0.03	8.18	7.2
0.04	3.63	3.18
0.05	1.96	1.63
0.06	1.20	0.944
0.08	0.595	0.411
0.10	0.372	0.219
0.15	0.196	0.080

Dose conversion coefficients for external exposure to photons
Inleiding tot de Stralingshygiëne [Introduction to Radiation Protection] (Bos et al., 2nd edition, 2007), p. 386

Photon energy (MeV)	K_a/Φ ($pGy\ cm^2$)	$H^*(10)/\Phi$ ($pSv\ cm^2$)
0.02	1.73	1.05
0.03	0.739	0.81
0.04	0.438	0.64
0.05	0.328	0.55
0.06	0.292	0.51
0.08	0.308	0.53
0.10	0.372	0.61
0.15	0.600	0.89