DBMR Hot Lab Safety training course

Department for BioMedical Research

UNIVERSITÄT BERN

François Achermann, Occupational Safety, Health Protection & Environmental Safety

December 3, 2019, 2.30–4 p.m., M.E. Müller-Haus, Room H810, Murtenstrasse 35, 3008 Bern

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DBMR Hot Lab Safety

Course program

1. Introduction
2. Physics
3. Radiation safety
4. Legislation
5. Dosimetry
6. NuclidCalc App
7. Security of high radioactive sources
8. Questions

Introduction

What IS «radiation»?

Electromagnetic waves

– AM radio, FM radio, shortwave radio, TV, cell phones, WiFi, microwave, visible light
*all **harmless** at low intensity*

– Near ultraviolet (UV)
***beneficial** at low doses, Vitamin D*

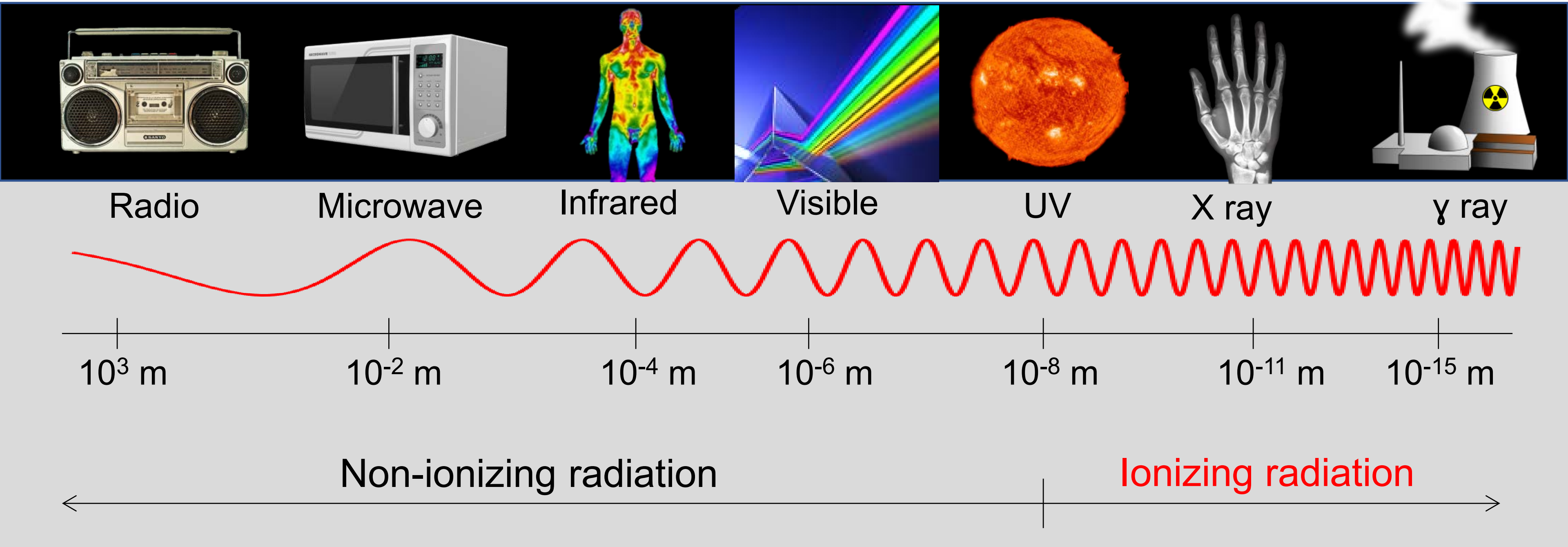
– Far UV, X rays, ɣ rays
***damaging** at all levels)*

Fast massive particles

– Electrons (β rays), protons, neutrons, α rays (^{4}He nuclei), heavy ion beams
***damaging** at all levels*

Radiation

Spectrum of electromagnetic waves

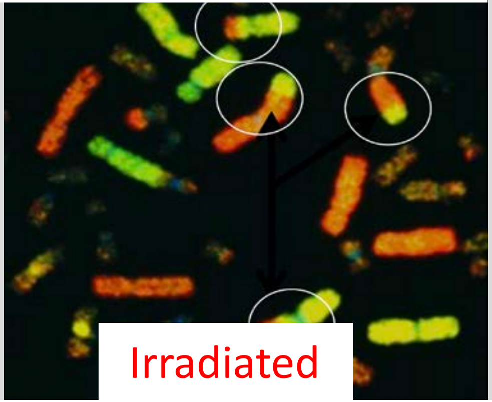


Ionizing radiation

What does the damage?

Ionizing radiation produces highly reactive *free radicals*
→ *pathological DNA* **double** *strand breaks, that are usually permanent, causing:*

Human lymphocyte chromosomes (Multi-Color FISH)



Non-irradiated

Irradiated

- **Cell Reproductive Death** (most common)
- **Genetic Mutation** (most subtle)
- **Cancer** (most unpleasant)

Single *strand breaks* usually heal in a few hours.

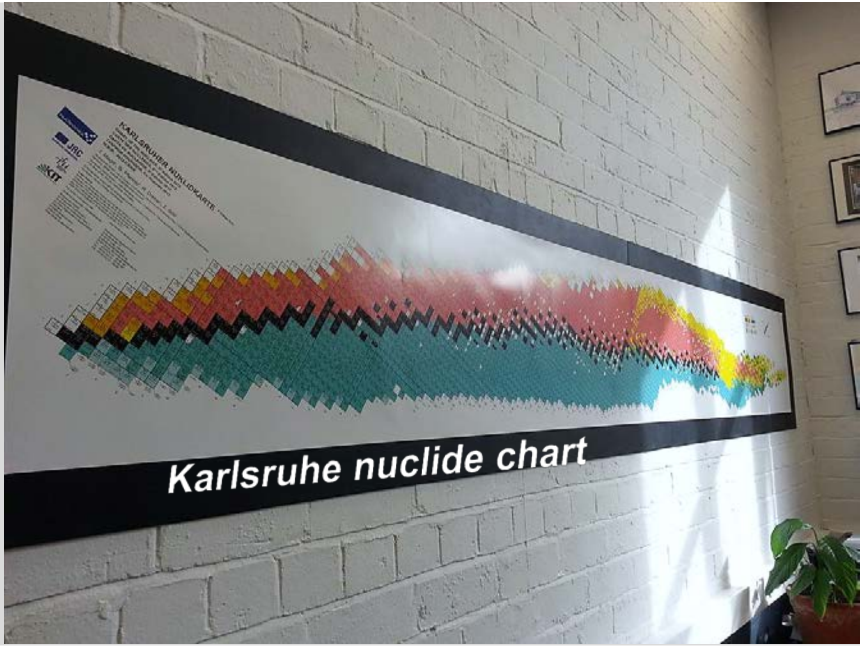
Radioactivity

What IS radioactivity?

Radioactivity
is the property of unstable atoms (=radionuclides) to spontaneously transform into other atomic nuclei and thereby emit ionizing radiation.

This transformation is called radioactive decay.

There are >3000 known nuclides, of which about 250 are stable.



Radionuclides

What is the origin of radionuclides?

Naturally occuring radionuclides:

- *Primordial nuclides* are remnants of nucleosynthesis in stars before the formation of the solar system. Half-life at least 2% of the age of the earth (4.6E+09 a).
- *Radiogenic nuclides* are formed by radioactive decay.
- *Nucleogenic nuclides* occur, when atoms react with natural neutrons from cosmic rays, nuclear fission or other sources.

Artificial radionuclides

- *Anthropogenic radionuclides*

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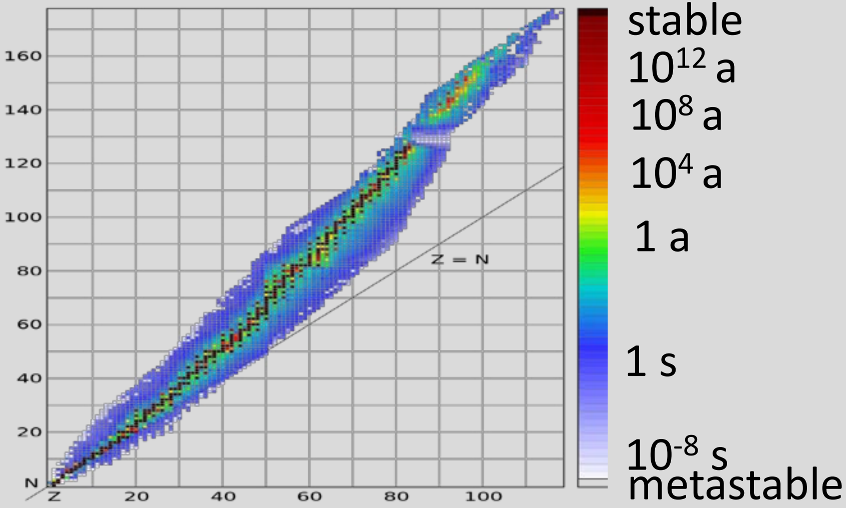
Physics

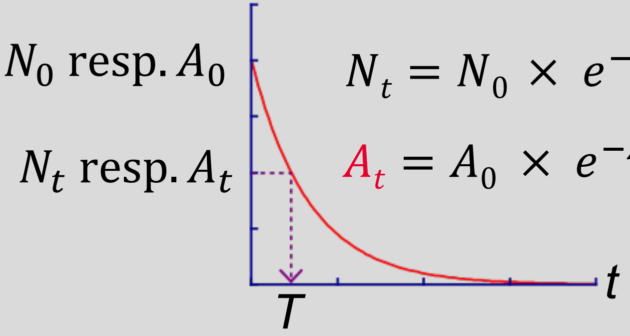
Radioactive decay

Half lifes of nuclides



The decay law

Activity A = disintegration rate. *N* = number of unstable nuclei. The *decay coefficient* λ resp. the *half-life T* is constant and characteristic of each radionuclide. *e* = Euler number. *t* = elapsed time.

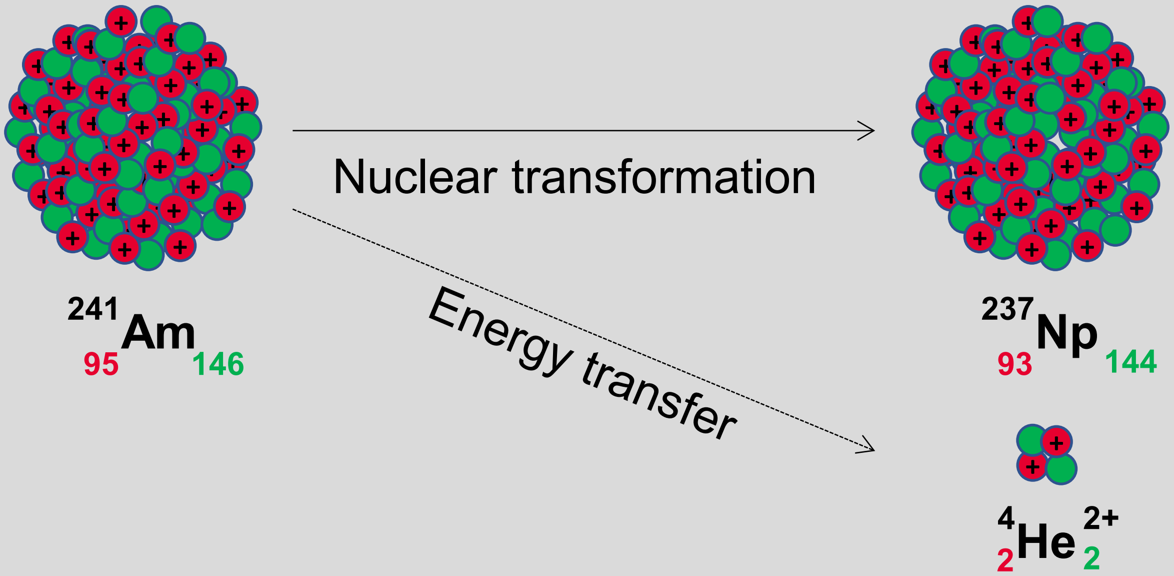


$$N_t = N_0 \times e^{-\lambda t}$$

$$A_t = A_0 \times e^{-\lambda t} = \frac{A_0}{2^{\frac{t}{T}}}$$

Radioactive decay

Decay modes: α decay



Mass number A

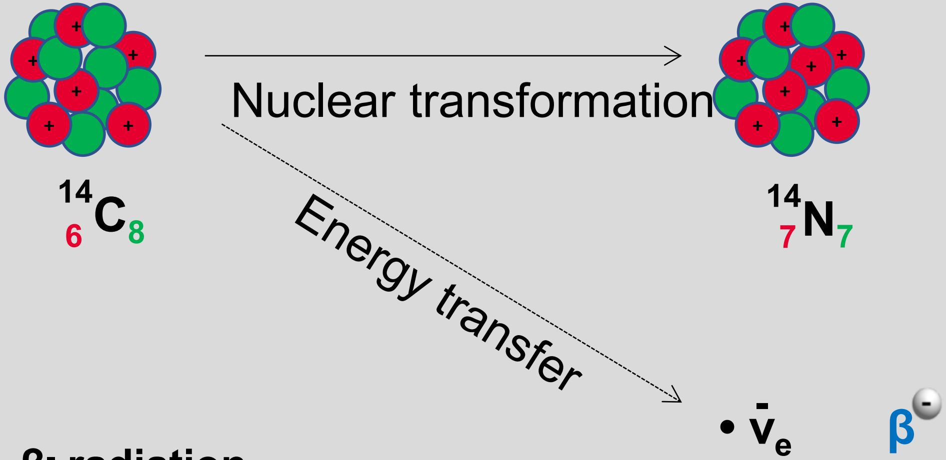
$$^{A}_{Z}X_{N}$$ Neutron number N

Proton number Z

α radiation
consists of alpha particles that are made up of two protons and two neutrons each and that carry a double positive charge

Radioactive decay

Decay modes: β⁻ decay



$$n \longrightarrow p + e^- + \bar{\nu}_e$$

n = Neutron
p = Proton
e^- = Electron
$\bar{\nu}_e$ = Antineutrino

β^- radiation
consists of negatively charged particles that are ejected from an atom's nucleus and that are physically identical to electrons.

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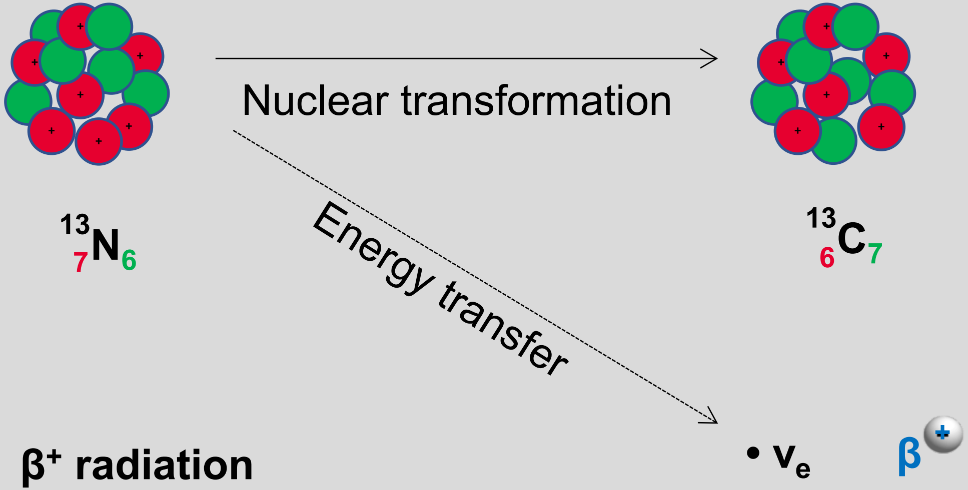
Radioactive decay

Decay modes: β^+ decay



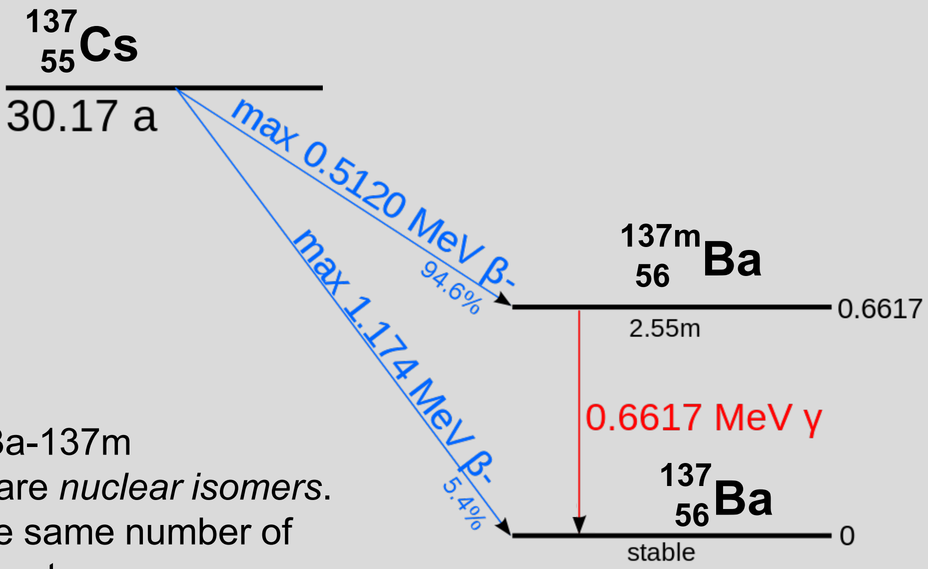
$$p \longrightarrow n + e^+ + \nu_e$$

p = Proton (+)
n = Neutron
e^+ = Positron (+)
ν_e = Neutrino

β⁺ radiation
consists of positively charged particles that are ejected from an atom’s nucleus and that are physically identical to positrons.

Radioactive decay

Decay modes: ɣ decay

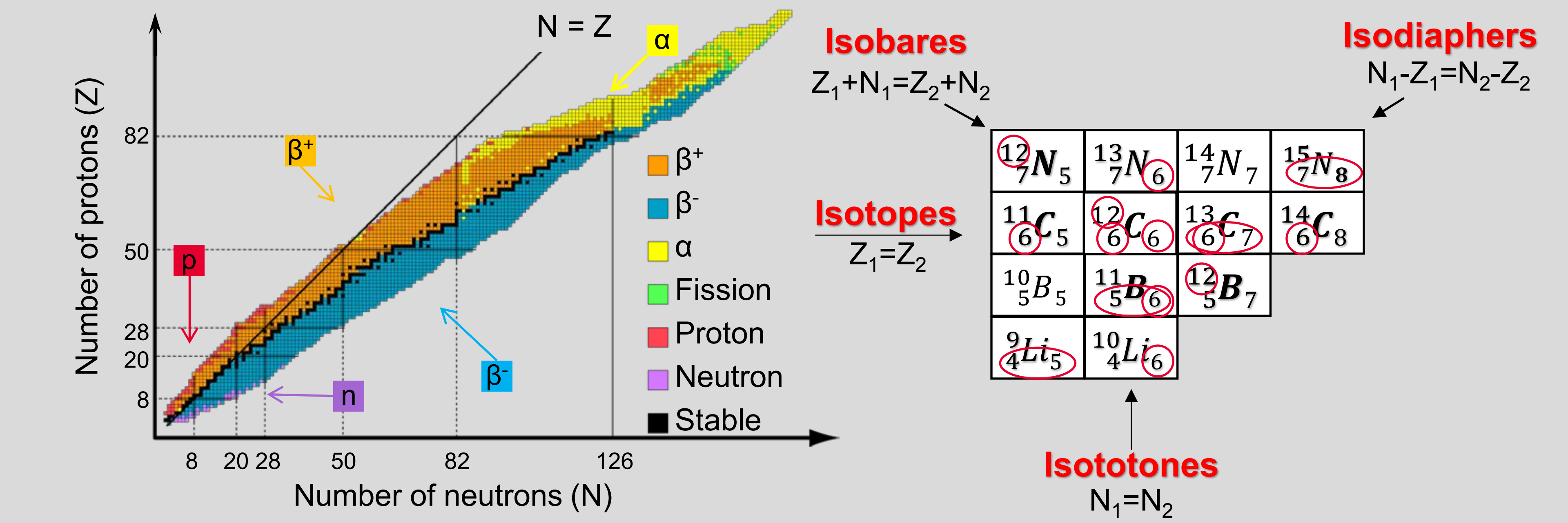


Ba-137 and Ba-137m (metastable) are *nuclear isomers*. They have the same number of protons and neutrons.

γ radiation consists of photons that originate from *within* the nucleus, wheras **X-ray** radiation consists of photons that originate from *outside* the nucleus.

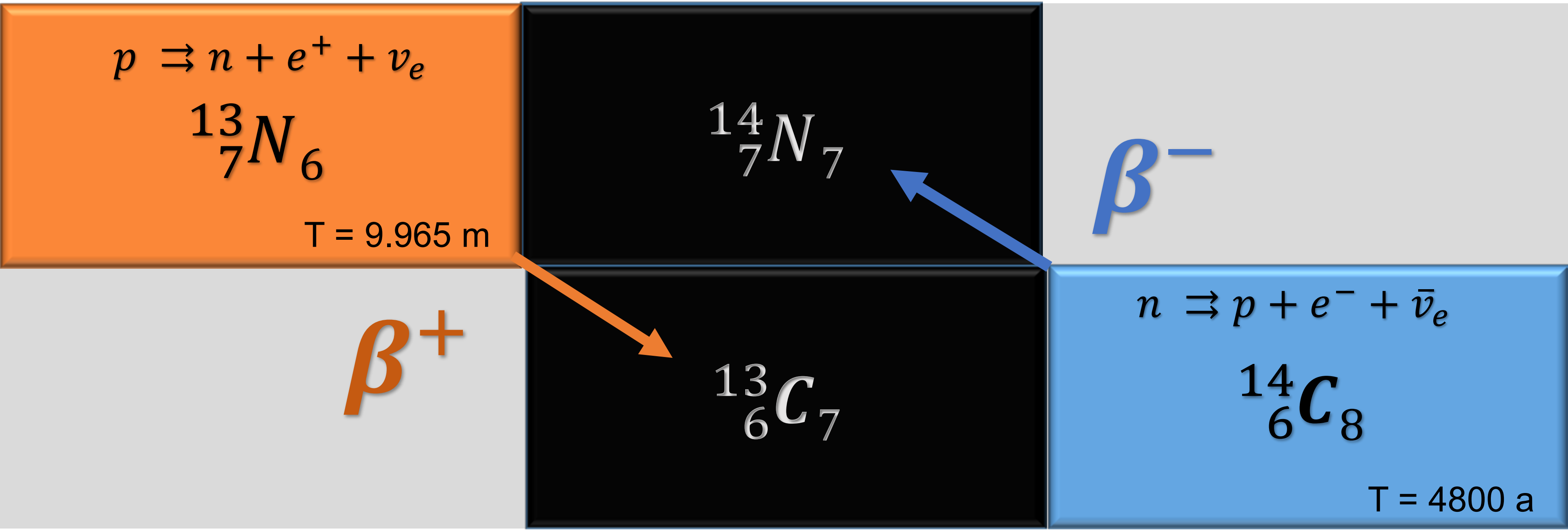
Radioactive decay

Karlsruhe nuclide chart



Radioactive decay

Karlsruhe nuclide chart



Radioactive decay

Radionuclides used at the DBMR

Nuclide	Half life	Major radiations	Energy (keV)	Shielding	Progeny
H-3	12.35 a	β^-	6	-	He-3
C-14	5730 a	β^-	156	Plexiglas 1cm	N-14
P-32	14.29 d	β^-	1’617	Plexiglas 1cm	S-32
S-35	87.44 d	β^-	167	Plexiglas 1cm	Cl-35
Ca-45	163 d	β^-	257	Plexiglas 1cm	Sc-45
Cr-51	27.70 d	ε, γ	γ: 320	Lead (5 cm)	V-51
Fe-55	2.70 a	ε	6	-	Mn-55
Co-57	270.9 d	ε, γ	γ: 122	Lead (5 cm)	Fe-57

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Radioactive decay

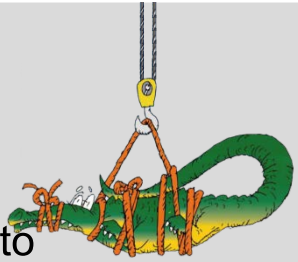
Radionuclides used at the DBMR

Nuclide	Half life	Major radiations	Energy (keV)	Shielding	Progeny
Fe-59	44.53 d	β^-, γ	β^-: 149 γ: 1’291	Lead (5 cm)	Co-59
Ga-68	68 m	ε, β^+, γ	β^+: 638 γ: 1’022	Lead (5 cm)	Zn-68
In-111	2.83 d	ε, γ	γ: 245	Lead (5 cm)	Cd-111
I-123	13.2 h	ε, γ	γ: 159	Lead (5 cm)	Te-123
I-124	4.18 d	ε, β^+, γ	γ: 1’022	Lead (5 cm)	Te-124
I-125	60.14 d	ε, γ	γ: 27	Lead (5 cm)	Te-125
I-131	8.04 d	β^-, γ	β^-: 192 γ: 637	Lead (5cm)	Xe-131
Cs-137	30.08 a	β^-, γ	β^-: 195 γ: 660	Lead (5 cm)	Ba-137

Radiation safety

Principles in radiation safety

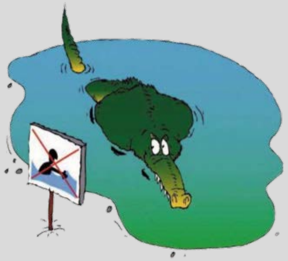
I. Justification



Principle of the necessity of a radiation application resp. justification of a an exposure to radiation (RPA art. 8).
A justification is required if the radiation dose is >0.01 mSv/a for bystanders or >0.1 mSv/a for occupationally exposed persons.

II. Optimization (ALARA)

Optimization of radiation protection measures to keep radiation doses «**A**s **L**ow **A**s **R**easonably **A**chievable - **ALARA**» (RPA art. 9).



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Principles in radiation safety

ALARA

Distance

Doubling the distance quaters the dose rate.

$$\dot{D}_2 = \dot{D}_1 \times \left(\frac{r_1}{r_2}\right)^2$$

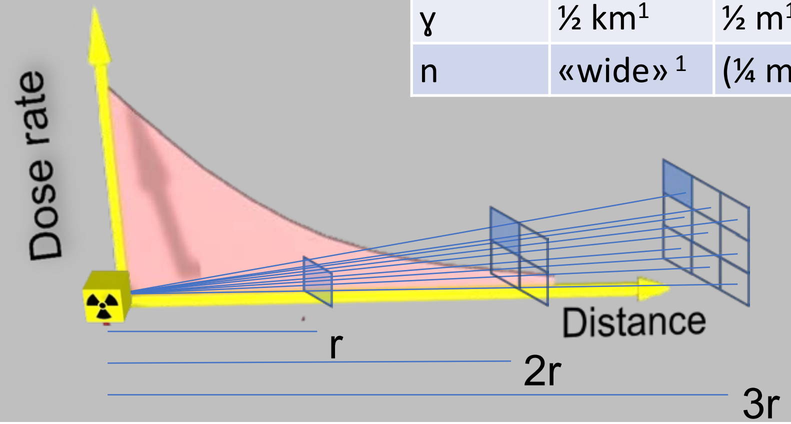
$\dot{D}$ = Dose rate [*mSv/h*]
r = Distance to radiation source

Not true if:

- fast massive particles
- r < 0.1 m

[1] Rule of thumb – Range depends on the energy of the radiation
[2] Tenth value layer (TVL)

Range	Air	Water
α	cm	µm
β	m[1]	mm[1]
TVL[2]	Air	Water
ɣ	½ km[1]	½ m[1]
n	«wide» [1]	(¼ m[1])



Principles in radiation safety

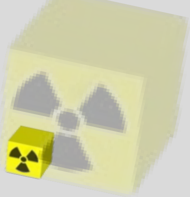
ALARA

Activity

The lower the activity, the lower the dose rate.

It is not reasonable to use higher activities just in order to speed up experiments.

Buy only as much as you need in the near future.



Regardless of natural isotopic decay, radiochemicals decay faster than their nonradioactive counterparts, due to

- direct interaction with radioactive emission (α, β, γ),
- interaction with excited species of the compound,
- thermodynamic instability and
- poor choice of storage conditions.

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Principles in radiation safety

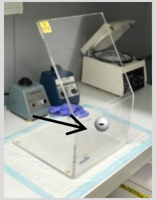
ALARA

Shielding

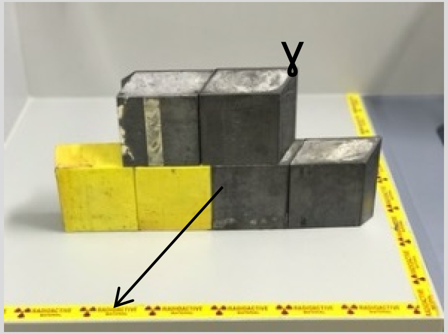
Since *alpha particles* ionize very strongly, they can be completely shielded with a sheet of paper.

All *beta particles* can be shielded with 1 cm perspex/plexiglas.

β



Gamma rays can not be completely shielded, they can only be attenuated. The higher the Z number of the shielding material, the more it attenuates γ rays.



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Principles in radiation safety

ALARA

Tenth-value layer (TVL) for photons

$$H_p = \frac{A \times t \times h_{10} \times \left(\frac{1m}{r}\right)^2}{10^{\frac{d}{TVL}}}$$

H_P: Equivalent dose in tissue at 10 mm deph
A: Activity
t: Time
h_{10}: Nuclide specific dose estimation factor
r: Distance from the source
d: Thickness of the shielding material

Energy of photons in keV	TVL in mm Pb
100	3 mm
500	16 mm
1000	38 mm
1500	51 mm
2000	59 mm
3000	65 mm

Principles in radiation safety

ALARA

Prevent spreading of radioactive materials

- Keep active and inactive work separated
- Always work over a spill tray within a ventilated enclosure
- Monitor the work area frequently for contamination
- Follow the rules

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Principles in radiation safety

ALARA

Wear appropriate protective clothing and dosimeters

Wear the dosimeter, laboratory coat, safety glasses, gloves, long trousers and closed shoes when you are working with radiochemicals

Principles in radiation safety

ALARA

Minimize time spent in handling radioactivity

Plan ahead. Perform cold runs to practice and to check procedures.

Never forget to do this

After completion of work, monitor yourself, wash and monitor again.

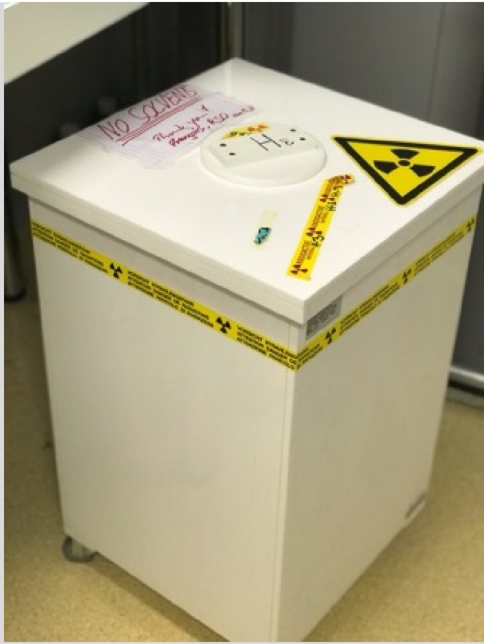
Principles in radiation safety

ALARA

Minimize accumulation of waste

Disposal of waste is subject to statutory control. Separate radioactive waste by nuclide, state of aggregate (solid/liquid) and combustibility.

Nuclides with a half life < 100 days are stored until they decayed below 10 kg · LL and then disposed of as non-radioactive waste. Tritium and carbon-14 are released to the environment in a controlled manner as well (<10 kg·LL per week).



Principles in radiation safety

Dose limits

Dose limits for occupational exposed persons

The system of dose limits for the protection of individuals is in accordance with the recommendations of the International Commission on Radiological Protection ICRP (RPA art. 10).

Dose limit values for occupational exposed healthy adults

The *effective dose E* must not exceed the limit of 20 mSv/a for adult individuals of category B resp. 5 mSv/a for individuals of cat. A. Pregnant women: ≤1 mSv to the unborn child.

The *equivalent dose H* must not exceed the following limits:

- For the lens of the eye: 20 mSv/a
- For the skin, hands and feet: 500 mSv/a

Operational radiation safety

Working zones

Depending on the *degree of contamination* which is present or expected, zones are classified into the following types:

Zone	Surface contamination C_S	Airborne contamination C_A	
0	$C_S < 1$ CS[1]	$C_A < 0.05$ CA[2]	
I	$C_S < 1$ CS	$0.05 \text{ CA} \leq C_A < 0.1$ CA	← D-Laboratory
II	$1 \text{ CS} \leq C_S < 10$ CS	$0.05 \text{ CA} \leq C_A < 0.1$ CA	← C-Laboratory
III	$10 \text{ CS} \leq C_S < 100$ CS	$0.1 \text{ CA} \leq C_A < 10$ CA	
IV	$C_S \geq 100$ CS	$C_A \geq 10$ CA	

[1] Guidance value (Bq/cm^2) for surface contamination as specified in RPO, Annex 3 Column 12; averaged over 100 cm^2.
[2] Guidance value (Bq/m^3) for chronic airborne activity as specified in RPO, Annex 3 Column 11.

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Operational radiation safety

Working areas

Within working zones, where *ambient dose rates* $\dot{D}$ are elevated, the following areas are designated with maximum permissible ambient dose rates:

Area	Ambient dose rate $\dot{D}$ at accessible locations
V	$\dot{D}$ < 10 µSv/h
W	10 µSv/h < $\dot{D}$ < 100 µSv/h
X	100 µSv/h < $\dot{D}$ < 1 mSv/h
Y	1 mSv/h < $\dot{D}$ < 10 mSv/h
Z	$\dot{D}$ > 10 mSv/h

← e.g. near X-ray systems without full protection.

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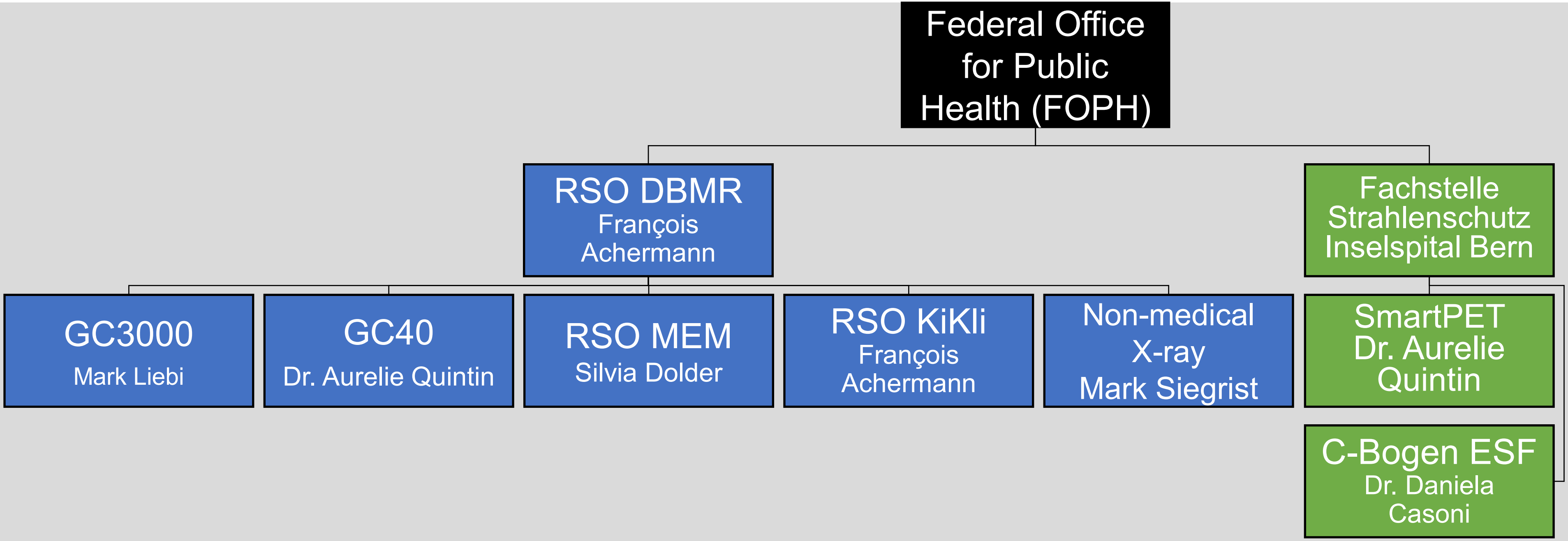
Radiation safety in the DBMR

Organization



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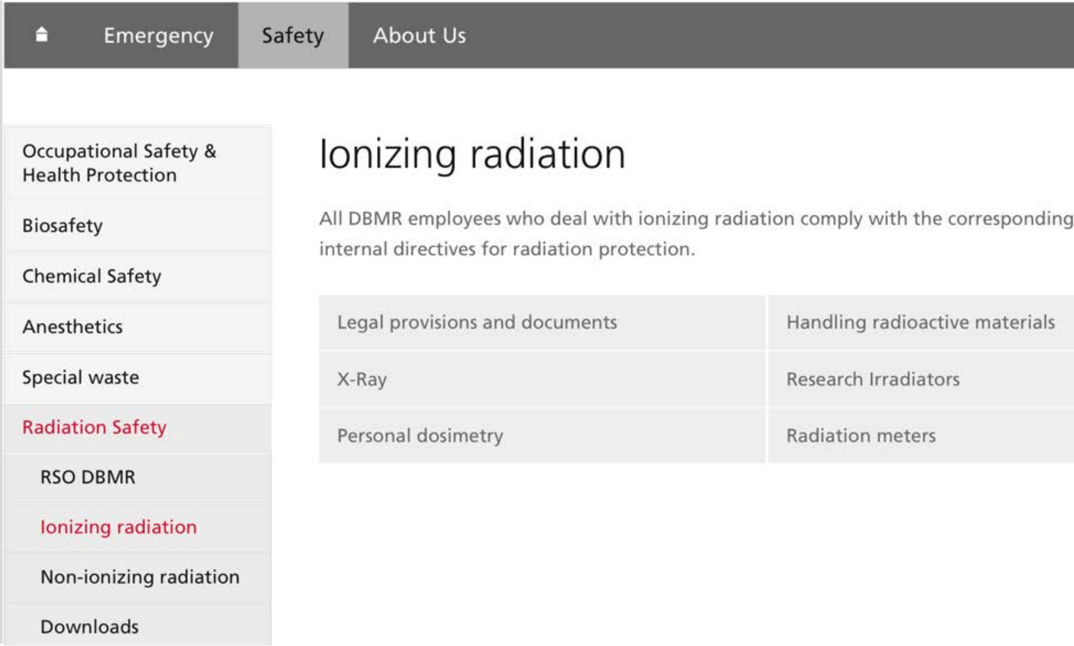
Informations on the DBMR safety microsite

www.safety.dbmr.unibe.ch

Internal directives for radiation safety

- Handling radioactive materials
- Thyroid triage for I-125
- Wipe-testing for H-3 and C-14
- Gammacell 40 research irradiator
- Gammacell 3000 research irradiator
- XCT 969
- Disposal H-3 and C-14 (UniBE)
- Radiation safety handbook (Insel)



Radiation Safety Officers (RSO)

Duties and responsibilities of the RSO

- Coordination of the licensing processes
- Control of the planning and execution of architectural radiation protection measures
- Designation of working areas and access authorization to controlled zones
- Designation of exposed persons and organization of the dosimetry
- Risk assessment for all activities with sources of ionizing radiation
- Quality assurance of the radiation meters
- Contamination monitoring
- Inventory of all radioactive materials
- Controlled release of radioactive waste to the environment
- Annual statement on the turnover of radioactive materials and on the release of radioactive waste to the environment
- Training and instruction of exposed persons
- Monitoring compliance with radiation safety regulations

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Radiation safety in the DBMR

How much of what can be used where?

Nuclide	LL[1]	LA[2,3]	C-Lab MEM		C-Lab KiKli		D-Labs
			in work[2,4]	Storage[2]	in work[2,4]	storage[2]	work[2,4] + storage[2]
H-3	100	100	1200	1200	200	1000	<100 [5]
C-14	1	9	50	50	50	250	<9 [5]
P-32	1000	2	100	100	100	200	<2 [5]
S-35	100	40	40	200	20	100	<40 [5]
Ca-45	100	2	50	100	50	50	<2 [5]
Cr-51	100	100	50	50	50	50	<50 [5]
Fe-55	1000	50	50	50	80	80	<50 [5]
Co-57	1	8	1	40	---	---	<8 [6]

[1] Exemption limit in Bq/g. RPO, annex 3

[2] Total activity in MBq

[3] Licensing limit, RPO, annex 3

[4] Handled activity per day

[5] At MEM+KiKli

[6] At MEM only

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Radiation safety in the DBMR

How much of what can be used where?

Nuclide	LL[1]	LA[2,3]	C-Lab MEM		C-Lab KiKli		D-Labs
			in work[2,4]	Storage[2]	in work[2,4]	Storage[2]	Storage[2] + work[2,4]
Fe-59	1	2	---	---	5	50	<2 [7]
Ga-68	10	60	1200	1200	---	---	<60 [6]
In-111	10	20	340	500	---	---	<20 [6]
I-123	100	50	50	50	---	---	<50 [6]
I-124	10	0.8	50	50	---	---	<0.8 [6]
I-125	100	0.7	70	250	20	50	<0.7 [5]
I-131	10	0.5	50	250	---	---	<0.5 [6]
Lu-177	100	5	350	500	---	---	<5 [6]

[1] Exemption limit in Bq/g. RPO, annex 3

[2] Total activity in MBq

[3] Licensing limit, RPO, annex 3

[4] Handled activity per day

[5] At MEM+KiKli

[6] At MEM only

[7] At KiKli only

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Operational radiation safety

Procurement and storage of radioactive materials

- The local RSO must be informed about the ordering of radioactive materials
- Upon delivery of radioactive material the local RSO must receive a copy of the delivery note and must be informed about the storage site
- Keep records of your inventory of radioactive materials at all time
- Clearly label containers (nuclide, total activity, date, owner, radiation propeller)
- Per fire compartment, a total activity <1 licensing limit (LA) can be stored/handled per day in a demarked area within a normal lab (→ D-Lab)
- Radioactive materials are stored exclusively in the approved and marked storage locations

Swiss legislation in radiation protection

Overview

Parliament
- Federal Act
- Radiation Protection Act (RPA)

Federal council
- Radiation Protection Ordinance (RPO)
- Ordinance on the Taxes in Radiation Protection
- Iodine Ordinance

FDHA[1]

Installations	Material	Education	Dosimetry
X-Ray Ordinance	Ordinance on the handling of sealed radiation sources in medicine	Ordinance on the training in radiation protection	Dosimetry Ordinance
Particle accelerator Ordinance	Ordinance on the handling of radioactive material		
Ordinance on non-medical equipment for generating ionizing radiation	Ordinance on radioactive waste		

FOPH[2]
- Guidelines

[1] Federal Department of Home Affairs

[2] Federal Office of Public Health

Revised legislation in radiation protection

What are the main changes since 2018?

- Authorization and supervision are based on risk-graded system
- Radiological security is strengthened
- Internationally harmonized exemption limits (LL)
- Lower limit of radiation dose for the eye lens
- Regular training is required in radiation protection
- Better protection of patients, staff and the environment through clinical audits
- Exposure to natural radiation at work is considered as occupational exposure
- When building, the radon load must be paid more attention.

Dosimetry

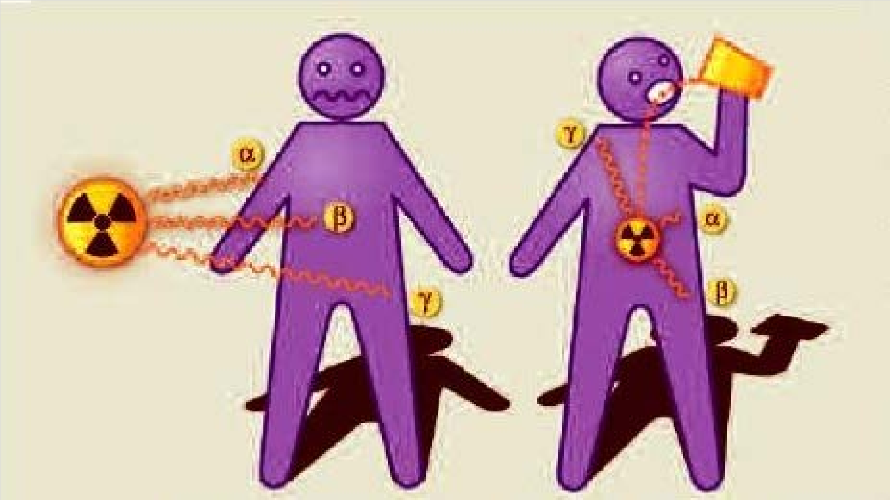
Exposure to ionizing radiation

Three types of exposure

1. External irradiation
2. Skin contamination with radionuclides
3. Incorporation of radionuclides by inhalation, ingestion or diffusion through skin

Doses depends:

- Nuclide species
- Activity / dose rate
- Type of exposure
- Exposure time



Dosimetry

External irradiation

Personal dosimeter

External irradiation is individually determined monthly by means of TLD-dosimeter. The dosimeter must be worn on the torso. Pregnant women wear the dosimeter at abdominal level.

Who must wear a dosimeter?

Persons working in controlled zone are occupationally exposed to radiation and must undergo dosimetry.

The local RSO designates the occupationally exposed persons.

Dose quantities

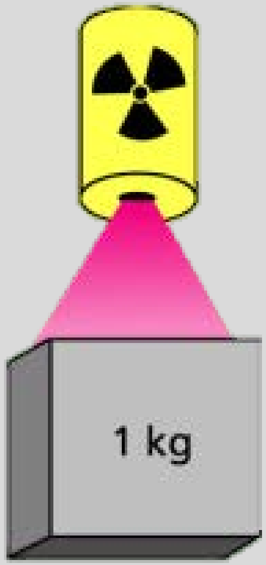
Absorbed dose D

The fundamental dose quantity given by:

$$D = \frac{d\bar{\varepsilon}}{dm}$$

where $d\bar{\varepsilon}$ is the mean energy imparted to matter of mass dm by ionizing radiation.

The SI unit for absorbed dose is joule per kilogram (J/kg), and its special name is gray (Gy).



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Dose quantities

Equivalent dose H

The *equivalent dose H* in a tissue or organ *T* is given by:

$$H_T = \sum_R W_R \times D_{T,R}$$

where $D_{T,R}$ is the mean *absorbed dose D* from radiation *R* in a tissue or organ *T*, and W_R is the radiation weighting factor. Since W_R is dimensionless, the unit for the equivalent dose is the same as for absorbed dose, J/kg. Its name is Sievert (Sv).

Radiation weighting factors W_R

Radiation type	W_R
X	1
γ	1
β	1
α	20
n	5-20*
p	2

* Depending on the kinetic energy of the absorbed neutrons

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Dose quantities

Personal dose equivalents $H_p(d)$

The *personal dose equivalent* $H_p(d)$ is the *absorbed dose D* in soft tissue at an appropriate depth $d\ [mm]$, below a specified point on the human body.

The *personal dose equivalent* $H_p(10)$ is used as an estimate of the *effective dose E*.

The *personal dose equivalent* $H_p(0.07)$, also called H_S, is used as an estimate of the dose to the skin and to the lens of the eye.

The unit of personal dose equivalent is *sievert* (Sv).

ɣ, X, if $r > 0.1\ \mathrm{m}$:

$$\boldsymbol{H_p(10) = A \times t \times h_{10} \times \left(\frac{1\,m}{r}\right)^2}$$

β, ɣ, X, if $r < 0.1\ \mathrm{m}$:

$$\boldsymbol{H_P(0.07) = H_s = A \times t \times h_{0.07}}$$

If skin contamination:

$$\boldsymbol{H_s = \frac{A}{surface} \times t \times h_{c0.07}}$$

h_{10}, $h_{0.07}$ and $h_{c0.07}$ values published in RPO, annex 3

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Dose quantities

Equivalent dose values h_{10}, $h_{0.07}$ and $h_{c0.07}$

Nuclide	h_{10} (mSv/h) / GBq in 1m distance	$h_{0.07}$ (mSv/h) / GBq in 10 cm distance	$h_{c0.07}$ (mSv/h) / (kBq/cm²)
H-3	<0.001	<1	<0.1
C-14	<0.001	200	0.3
P-32	<0.001	1000	1.6
S-35	<0.001	200	0.3
Ca-45	<0.001	700	0.8
Cr-51	0.005	3	<0.1
Fe-55	<0.001	20	<0.1
Co-57	0.021	100	0.1

Nuclide	h_{10} (mSv/h) / GBq in 1m distance	$h_{0.07}$ (mSv/h) / GBq in 10 cm distance	$h_{c0.07}$ (mSv/h) / (kBq/cm²)
Fe-59	0.175	1000	1.1
Ga-68	0.149	1000	1.5
In-111	0.082	400	0.3
I-123	0.043	400	0.3
I-124	0.170	300	0.5
I-125	0.033	4	<0.1
I-131	0.062	1000	1.4
Cs-137	0.092	2000	1.5

Dose quantities

Equivalent dose $H_p(10)$

Example:

A person stays 42 hours at a distance of 0.4 meters from an unshielded 50 MBq Fe-59 source. What is the equivalent dose $H_P(10)$?

$$H_P(10) = Activity\ \ A\,[GBq]\ \times\ time\,[h]\ \times\ h_{10}\left[\frac{mSv/h}{GBq}\right] \times \left(\frac{1\,m}{r}\right)^2$$

$$H_P(10) = 0.05\,GBq\ \times\ 42\text{h}\ \times\ 0.175\,\frac{mSv}{h\ \times\ GBq}\ \times\ \left(\frac{1\,m}{0.4\,m}\right)^2 = \mathbf{2.3\,mSv}$$

Nuclide: Fe-59
A: 50MBq = 0.05 GBq
T: 42 h
r: 0.4 m
h_{10}: 0.175 $\frac{mSv}{h \times GBq}$ @ 1m
$H_p(10)$ = ?

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Dose quantities

Skin dose H_S

Example:

A person holds her hand for 2 hours at a distance of 10 cm to a 50 MBq Ca-45 source. What is the skin dose H_S of the hand?

$$H_S = Activity\ [GBq]\ \times\ t\ [h]\ \times\ h_{0.07} \left[\frac{mSv/h}{GBq\ @\ a\ distance\ of\ 10\ cm}\right]$$

$$H_S = 0.05\ GBq \times\ 2\ \mathrm{h}\ \times\ \frac{700\ mSv/h}{GBq\ at\ a\ distance\ of\ 10\ cm} = \mathbf{70\ mSv}$$

Nuclide: Ca-45

A: 50MBq = 0.05 GBq

t: 2 h

r: 10 cm

$h_{0.07}$: 700 $\frac{mSv}{h \times GBq}$ @ 10 cm

H_S resp. $H_p(0.07)$ = ?

Dose quantities

Skin dose H_S due to contamination

Example:

A person contaminates a skin area of 50 cm^2 with 100 MBq of P-32. 5 minutes pass until decontamination. What is the skin dose H_S?

$$H_S = \frac{Activity\ [kBq]}{Area\ [cm^2]} \times t\ [h] \times h_{c0.07} \left[\frac{mSv/h}{kBq/cm^2}\right]$$

$$H_S = \frac{100'000\ kBq}{50\ cm^2} \times 0.083\text{h} \times \frac{1.6\ mSv/h}{kBq/cm^2} = \mathbf{266\ mSv}$$

Nuclide: P-32

A: 100MBq = 10^5 kBq

t: 5 min = 0.083 h

Area: 50 cm^2

$h_{c0.07}$: 1.6 $\frac{mSv/h}{kBq/cm^2}$

H_S = ?

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Dose quantities

Effective dose E

The *effective dose E* is the tissue-weighted sum of the *equivalent doses* H_T in all specified tissues and organs is given by the expression

$$\boldsymbol{E = \sum_T W_T \times H_T}$$

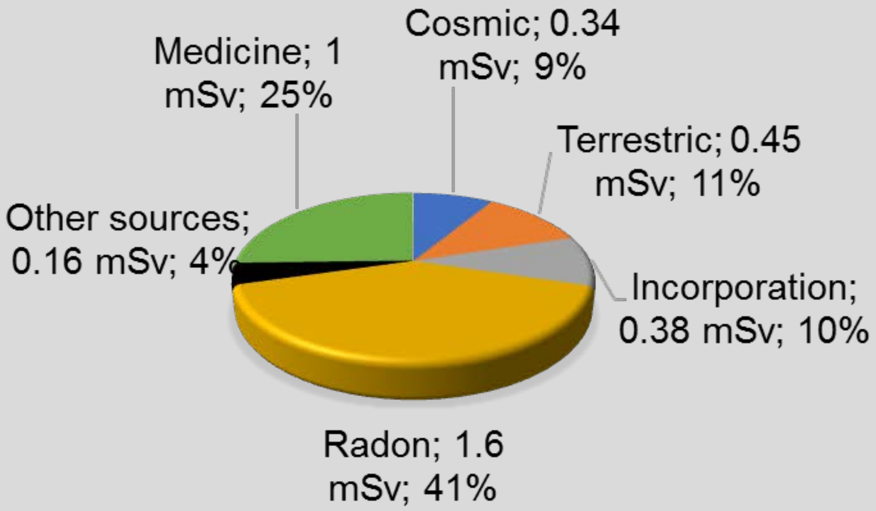
The unit of the effective dose is J/kg, and it's name is *Sievert (Sv)*.

Tissue weighting factors W_T

Tissue or organ	W_T
Brain, skin, bone surface, salivary glands	0.01
Bladder, liver, oesophagus, thyroid	0.04
Gonads	0.08
Bone-marrow, colon, lung, breast, stomach, remainder tissues	0.12

Dose quantities

How bad is how much?



	nSv/a	
	µSv/a	Return flight Zürich-Los Angeles = 60 µSv
	1 mSv/a	Annual limit value for the population
	3 mSv/a	Approx. natural annual dose
	20 mSv/a	Limit for occupationally exposed persons
	200 mSv	1% additional risk of cancer
	1 Sv	Deterministic health damage
	7 Sv	Instant death

Internal irradiation

Intake of radioactive material into the body

Committed equivalent dose $\boldsymbol{H_T(\tau)}$

The time integral of the equivalent dose rate in a particular tissue or organ that will be received following the intake of radionuclides into the body, where $\boldsymbol{\tau}$ is the integration time in years.

Committed effective dose $\boldsymbol{E_{50}}$

The committed effective dose E_{50} is the sum of the products of the committed equivalent doses $\boldsymbol{H_T(\tau)}$ and the appropriate tissue weighting factors $\boldsymbol{W_T}$. The commitment period following the intake is taken to be 50 years for adults.

Inhalation: $E_{50} = A_{inh} \times e_{inh}$

Ingestion: $E_{50} = A_{ing} \times e_{ing}$

$$[Sv] = [Bq] \times [Sv/Bq]$$

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Internal irradiation

Effective dose values e_{inh} and e_{ing}

Nuclide	e_{inh} (Sv/Bq)	e_{ing} (Sv/Bq)
H-3	4.1E-11	4.2E-11
C-14	5.8E-10	5.8E-10
P-32	2.9E-09	2.4E-09
S-35	1.2E-10	7.7E-10
Ca-45	2.3E-09	7.6E-10
Cr-51	3.6E-11	3.8E-11
Fe-55	9.2E-10	3.3E-10
Co-57	6.0E-10	2.1E-10

Nuclide	e_{inh} (Sv/Bq)	e_{ing} (Sv/Bq)
Fe-59	3.2E-09	1.8E-09
Ga-68	8.1E-11	1.0E-10
In-111	3.1E-10	2.9E-10
I-123	1.1E-10	2.1E-10
I-124	6.3E-09	1.3E-08
I-125	7.3E-09	1.5E-08
I-131	1.1E-08	2.2E-08
Cs-137	6.7E-09	1.3E-08

The nuclide specific values e_{inh} and e_{ing} are listed in RPO, annex 3, columns 4 and 5

Internal irratiation

Committed effective dose E_{50}

Example

A person inhales 70 MBq of I-125. What is the comitted effective dose E_{50}?

$$E_{50} = Activity\ [Bq] \times e_{inh}[Sv/Bq]$$

$$E_{50} = 7 \cdot 10^{7} Bq \times 7.3 \cdot 10^{-9}\, Sv/Bq = \mathbf{511\ mSv}$$

Nuclide: I-125

A: 70 MBq = $7 \times 10^{7}\ Bq$

e_{inh}: $7.3 \times 10^{-9}\ Sv/Bq$

E_{50} = ?

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Internal irradiation

Committed effective dose E_{50}

Example

A person ingests 1 mCi of H-3. What is the committed effective dose E_{50}?

$$E_{50} = Activity\ [Bq] \times e_{ing} [Sv/Bq]$$

$$E_{50} = 3.7 \times 10^{7}\ Bq\ \times\ 4.2 \cdot 10^{-11}\, Sv/Bq = \mathbf{42\ mSv}$$

Nuclide: H-3
A: 1 mCi = $3.7\ \times 10^{7}\ Bq$
e_{ing}: $4.2 \times 10^{-11}\ \ Sv/Bq$
E_{50} = ?

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Internal irradiation

Who must monitor internal irradiation?

Nuclide	Annual turnover	If volatile
H-3	20 GBq	2 GBq
C-14	1.8 GBq	180 MBq
P-32	400 MBq	40 MBq
S-35	8 GBq	800 MBq
Ca-45	400 MBq	40 MBq
Cr-51	20 GBq	2 GBq
Fe-55	10 GBq	1 GBq
Co-57	1.6 GBq	160 MBq

Nuclide	Annual turnover	If volatile
Fe-59	400 MBq	40 MBq
Ga-68	12 GBq	1.2 GBq
In-111	4 GBq	400 MBq
I-123	1 GBq	
I-124	16 MBq	
I-125	14 MBq	
I-131	10 MBq	
Lu-177	1 GBq	100 MBq

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Dosimetry

Summary

Unit	Used for	Base units of measurement	Derivited units old | new (SI)		Conversion
Activity A	Radioactive materials	Activity **A** Disintegrations per time «disintegration rate» $\boldsymbol{s^{-1}}$	Curie **Ci**	Becquerel **Bq**	$1\ Ci = 3.7\ \times 10^{10}\ Bq$ (=activity of 1 gr. radium)
Absorbed dose D	Irradiation of material	Energy per mass $\boldsymbol{J\ \times kg^{-1}}$	Rad **Rd**	Gray **Gy**	$1\ Gy = 100\ rd$ (**r**adiation **a**bsorbed **d**ose)
Dose rate $\dot{D}$ $\boldsymbol{\dot{D} = D/t}$	Irradiation of material	Absorbed dose per mass and time $J\ \times kg^{-1} \times s^{-1}$	$\boldsymbol{Rd/h}$	$\boldsymbol{Gy/h}$	t: duration of exposure
Ion dose I	Radiation meters	Charge per mass $\boldsymbol{As\ \times kg^{-1}}$	Roentgen **R**		$1\frac{As}{kg} = 3.876\ \times 10^{3}\ R$

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Dosimetry

Summary

Unit	Used for	Base units of measurement	Derivited units old |	new (SI)	Conversion
Dose equivalent H	Irradiation of organs	A kind of damage unit, depending on the type of radiation $\boldsymbol{J \times kg^{-1}}$	**rem**	Sievert **Sv**	$1\ Sv = 100\ rem$ (**r**adiation **e**quivalent **m**an)
Effective dose E	Irradiation of people	Transforms organ irradiation into a whole-body dose of the same late-risk $\boldsymbol{J \times kg^{-1}}$		Sievert **Sv**	
Comitted effective dose E_{50}	Irradiation of peope	Sum of the products of the committed equivalent doses $\boldsymbol{H_T(\tau)}$ and the appropriate tissue weighting factors $\boldsymbol{W_T}$ over 50 years. $\boldsymbol{J \times kg^{-1}}$		Sievert **Sv**	

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NuclidCalc App

By Federal Office of Public Health

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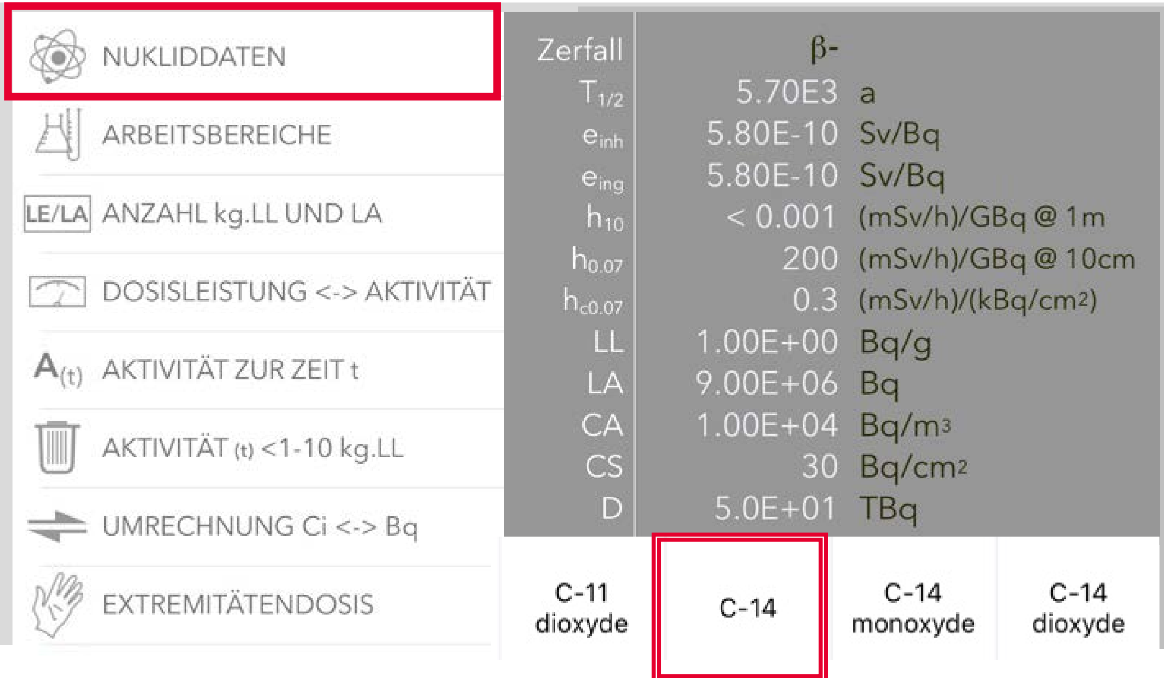

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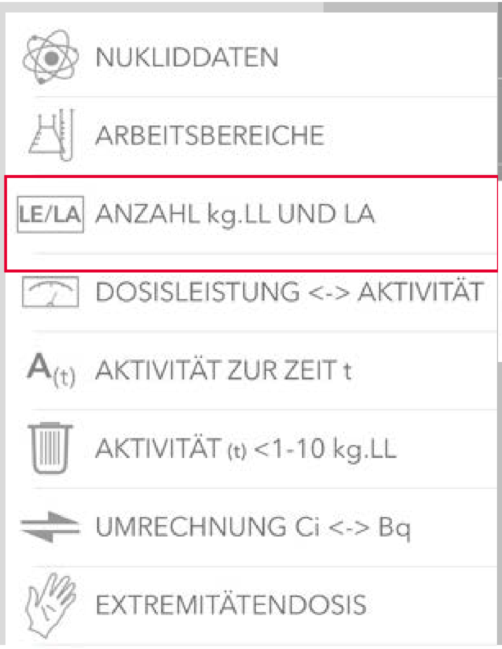
NuclidCalc App

Activity <> kg·LL and LA

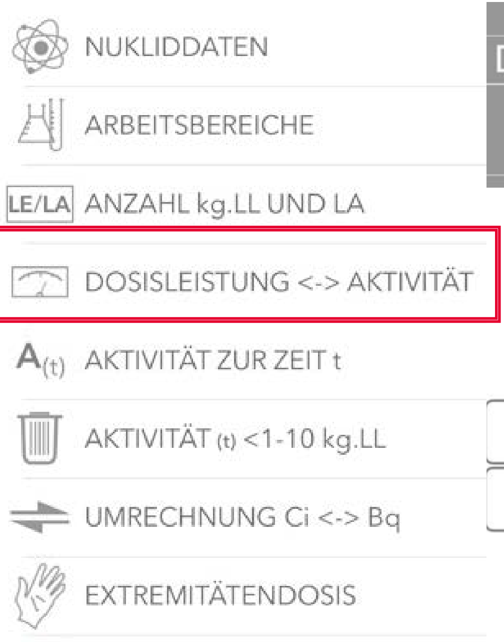
How many licensing limits are handled and how many kg·LL of radioactive waste is produced?



NuclidCalc App

Dose rate <> Activity

What ambient dose rate $\dot{D}$ produces my unshielded source at a certain distance d?



NuclidCalc App

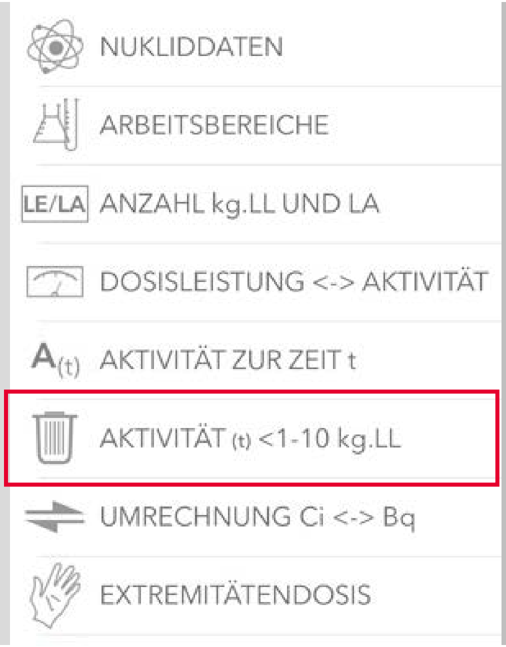
Activity A at time point t

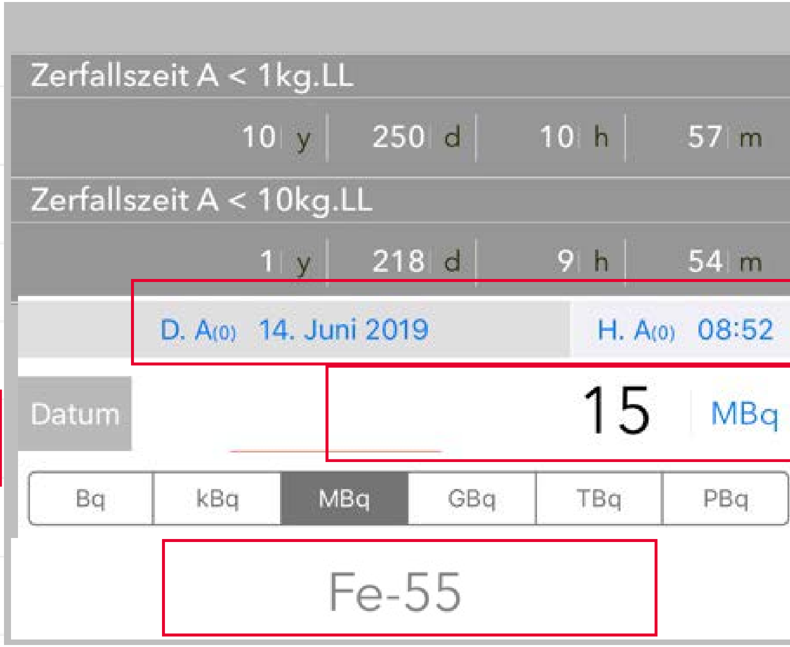
What is the activity A at time point t?

NuclidCalc App

Activity A_t < 1-10 kg·LL

When has your radioactive waste decayed below 1 resp. 10 kg·LL .





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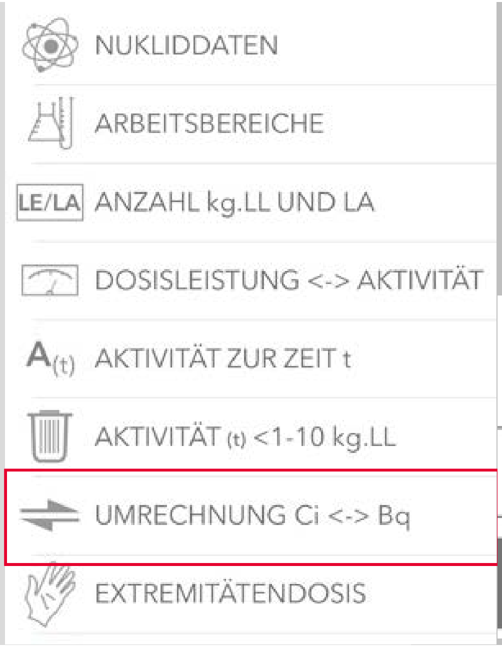
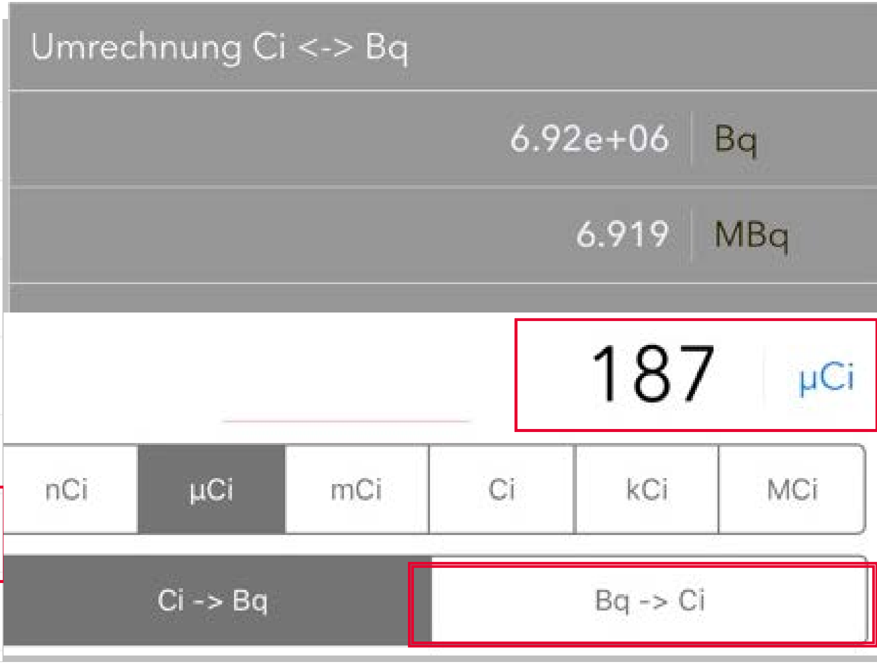
NuclidCalc App

Conversion Curie <> Bequerel

Convert Ci<->Bq





NuclidCalc App

Equivalent dose H_S

Estimate the skin equivalent dose H_S for fingers and hands, if not protected.

Security of high radioactive sealed sources

Dangerous quantities of radioactive material

Definition

High-activity sealed source means a sealed radioactive source whose activity is greater than the activity D-value specified in the radiation protection ordinance, Annex 9.

Protection class (CH)	Activity in D-values
A	$A \geq 1000$ D
B	10 D $\leq A <$ 1000 D
C	1 D $\leq A <$ 10 D

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Security of high radioactive sealed sources

Dangerous quantities of radioactive material

Gammacell 40 Research Irradiator

Nuclide: Cs-137
A_0: 109.9 TBq (1st of November 2006)
Half life T: 30.08 a
A_t: 81.4 TBq (December 3, 2019)
D-value of Cs-137: 0.1 TBq
81.4 TBq of Cs-137 ≡ 814 D-values
⇒ *Protection class B (CH)*

Gammacell 3000 Research Irradiator

Nuclide: Cs-137
A_0: 55 TBq (1st of December 1996)
Half life T: 30.08 a
A_t: 32.4 TBq (December 3, 2019)
D-value of Cs-137: 0.1 TBq
32.4 TBq of Cs-137 ≡ 324 D-values
⇒ *Protection class B (CH)*

Sum D-values of both high radioactive sealed sources in the gamma irradiation room

814 D-values + 324 D-values = 1138 D-values ⇒ *Protection class A (CH)*

Security of high radioactive sealed sources

Comparison of security requirements (class A and B)

Security requirement	Protection class A	Protection class B
Number of physical barriers	≥ 2	
Resistance class of physical barrier	RC4 (≥ 1 barrier)	RC3 (≥ 1 barrier)
Lock	Mechanical, 2-factor authentication (key, badge, PIN, etc.)	Mechanical
Access protocol	Electronic storage of every access	-
Intrusion detection	After detection ≥ 2 barriers have to be overcome	After detection ≥ 1 barriers has to be overcome
Trustworthiness check of the authorized persons	Identity, CV, references, criminal record, debt record	Identity, CV, references
Security system check	Every day	Every week

Thank you

for your attention!

François Achermann, Department for BioMedical Research

3rd of December, 2019, M.E. Müller-Haus, Murtenstrasse 35, 3008 Bern

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