CERN

Claudia Ahdida

Radiation Protection Physicist
at CERN

My career in a nutshell

2002

Diploma studies at Frankfurt University

Heavy ion physics at the NA49 experiment at CERN, K0s production in Pb+Pb central collisions

2007

Doctoral studies at ETH Zurich

Elementary particle physics at CERN involving the NA61/T2K experiments

2011

Consultant at Oliver Wyman

Consultant for a leading global consultancy firm in the financial sector

2013

Fellow RP Physicist at CERN

Radiological assessment and design optimization of proposed facilities

2016

RP Physicist at PSI

Global planning of radiological installations and PSYS, Co-project leader of the DRPS at SwissFEL

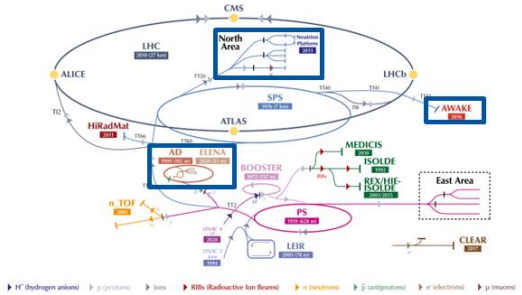
Since 2018

Staff RP Physicist at CERN

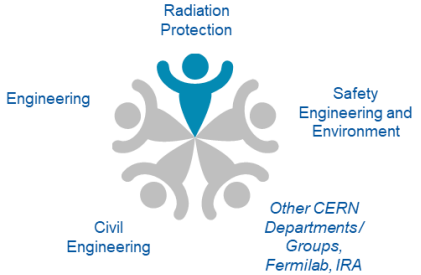
RP responsible for various CERN facilities and projects

RP Physicist at CERN

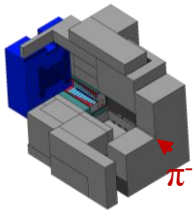
CERN accelerator complex

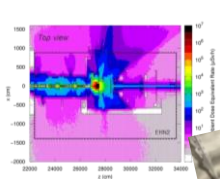


Copyright CERN. Source CERN CDS



- RP responsible
  - North Experimental Area (EHN1, EHN2, ECN3 and secondary transfer lines)
  - AD and ELENA
  - AWAKE
  - CNGS dismantling
  - Physics Beyond Colliders (BDF, HIKE, SHADOWS, NA60++, AMBER)
  - Muon Collider





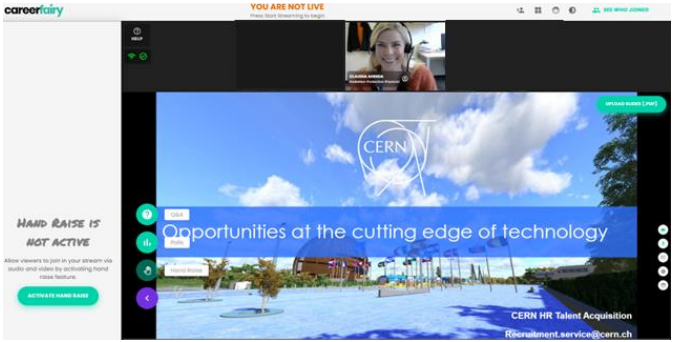
Outreach activities

Femmes et filles de science et technologie

Nuit de la science

BBC Radio 5

CareerFairy Webinar



CrossING Event Ruhr-Universität Bochum

Guide AD

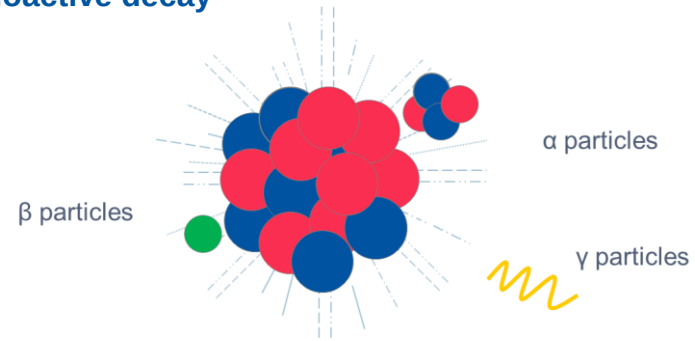
Futur en tous genres

CERN 2019 Open Days Stand

Radioactivity

Some types of atoms spontaneously decay (or transform) and emit particles and radiation through a process called radioactive decay or radioactivity. Ionizing radiation is radiation that carries enough energy to free electrons from atoms or molecules, thereby causing them to become charged

Radioactive decay

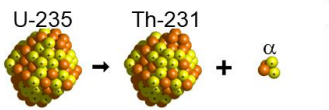


An atom consists of a nucleus surrounded by a cloud of electrons. Some nuclei are unstable: they spontaneously disintegrate (or transform) and emit particles (= radiation). Such nuclei are called radioactive nuclei

The only way to detect and measure radiation is by using specific instrumentation

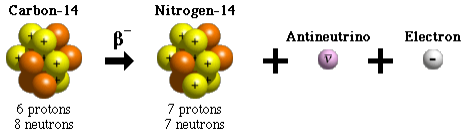
Decay types

α decay: Emission of an α particle (2 protons + 2 neutrons)



$A_{new} = A_{old} - 4$ und $Z_{new} = Z_{old} - 2$

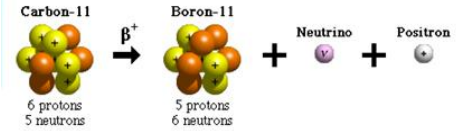
β decay: Emission of 1 electron or positron and 2 neutrinos



$A_{new} = A_{old}$ und

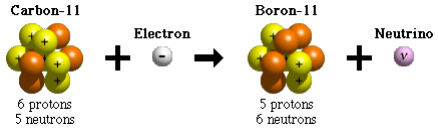
$Z_{new} = Z_{old} + 1$

oder



$Z_{new} = Z_{old} - 1$

Electron capture: An electron from the atomic shell is captured by a proton, resulting in its transformation into a neutron. X-rays or Auger electrons emission may be emitted as outer electrons fill inner-shell vacancy



$A_{new} = A_{old}$ und

$Z_{new} = Z_{old} - 1$

γ decay: In gamma decay, an atomic nucleus transitions from a higher to a lower energy state by emitting a high-energy photon (gamma particle). The composition of the nucleus remains unchanged

$A_{new} = A_{old}$ and $Z_{new} = Z_{old}$

All pictures from Jefferrson lab webseite

Activity and effective dose

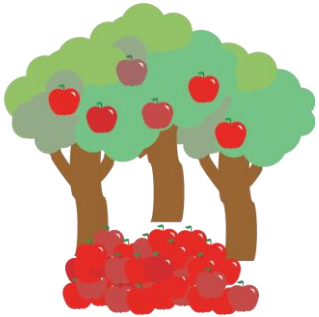
Activity

- The decay rate is called activity:

$$A = -\frac{\mathrm{d}N}{\mathrm{d}t}$$

A: activity, decay per time unit
N: number of radioactive isotopes
t: time

- The **Becquerel [Bq]** is the unit for radioactivity:
  1 Bq = 1 decay per second



The activity (the number of decays per second) can be compared to the number of apples falling from a tree.

- The proportionality factor is called decay constant (λ) and defines the probability of decay per unit of time

$$A = -\frac{\mathrm{d}N}{\mathrm{d}t} = \lambda \cdot N$$

λ: Decay constant, which defines the decay rate

Mit $N(t=0) = N_0$

$$N(t) = N_0 \cdot e^{-\lambda \cdot t}$$

$$A(t) = A_0 \cdot e^{-\lambda \cdot t} \quad \leftrightarrow \quad A(t) = A_0 \cdot 2^{-\frac{t}{\tau_{1/2}}}$$

More common form:

with half-life $\tau_{1/2} = ln(2)/\lambda$

Activity and effective dose

Activity

- The decay rate is called activity:

$$A = -\frac{\mathrm{d}N}{\mathrm{d}t}$$

A: activity
N: number of radioactive isotopes
t: time

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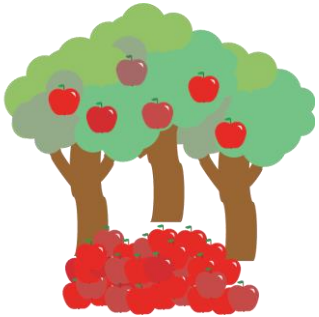
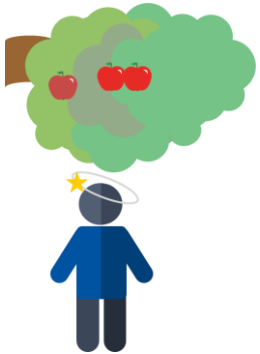


The activity (the number of decays per second) can be compared to the number of apples falling from a tree.

Effective dose

- The effective dose is a measure of the effects of ionising radiation on health and the human body
- **Sievert [Sv]** is the unit of the effective dose

1 mSv = 1000 µSv = 1’000’000 nSv



The effective dose can be compared to the marks made on the body, depending on the size of the apples and which part of the body they hit as they fall

Dosimetric quantities

Absorbed dose

$$D = \frac{\Delta E}{\Delta m}$$

$$[J * kg^{-1}] = [Gy]$$

Physical quantity of energy transferred by ionizing radiation, which does not take biological aspects into account (the same dose does not necessarily mean the same risk)

Dose equivalent

ICRP60: $H_T = \sum_R w_R \times D_{T,R}$

ICRP26: $H_T = D_T \times Q \times N$

$$[J * kg^{-1}] = [Sv]$$

Absorbed dose in organ/tissue adjusted for radiation type w radiation weighting factors

Effective dose

ICRP60: $\mathrm{H} = \sum_T w_T \times H_T$

ICRP26: $H_E = \sum_T w_T \times H_T$

$$[J * kg^{-1}] = [Sv]$$

Whole body dose is obtained by organ/tissue weighting factors

Protection quantities

	ICRP 26 Q	ICRP 60 w_R	ICRP 103 w_R	Part 20 w_R
Photons, all energies	1	1	1	1
Electrons and muons, all energies	1	1	1	1
Neutrons, all (unknown) energies	10	Step function	continuous function	10
< 10 keV		5	2.5	2 to 2.5
10 - 100 keV		10	2.5 to 10	2.5 to 7.5
100 - 2 MeV		20	10 to 20	7.5 to 11
2 to 20 MeV		10	7 to 17.5	8 to 9
> 20 MeV		5	5 to 7	3.5 to 8
Protons, energy > 2 MeV	10	5	2	10
Alpha particles, fission fragments heavy nuclei	20	20	20	20

w_T	ICRP 26	ICRP 60	ICRP 103	Part 20
Gonads	0.25	0.20	0.08	0.25
Breast	0.15	0.05	0.12	0.15
Red bone marrow	0.12	0.12	0.12	0.12
Lung	0.12	0.12	0.12	0.12
Thyroid	0.03	0.05	0.04	0.03
Bone surfaces	0.03	0.01	0.01	0.03
Colon	-	0.12	0.12	-
Stomach	-	0.12	0.12	-
Bladder	-	0.05	0.04	-
Oesophagus	-	0.05	0.04	-
Liver	-	0.05	0.04	-
Brain	-	-	0.01	-
Kidney	-	-	-	-
Salivary Glands	-	-	0.01	-
Skin	-	0.01	0.01	-
Remainder	0.30[6]	0.05[7]	0.12[8]	0.30[9]

*ICRP: International Commission on Radiological Protection

Dosimetric quantities

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ICRP26: $H_E = \sum_T w_T \times H_T$

$$[J * kg^{-1}] = [Sv]$$

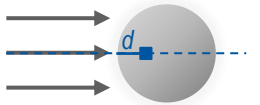
Whole body dose is obtained by organ/tissue weighting factors

Protection quantities

Ambient dose equivalent H*(d)

Operational quantity

Dose equivalent at a depth d in the ICRU[1] sphere.
This is an operational quantity for area monitoring



ICRU sphere ,Ø - 300 mm
tissue equiv. material

- According to ICRP the "**effective dose** is used for regulatory purposes worldwide" to provide means of demonstrating compliance with dose limits

*ICRP: International Commission on Radiological Protection

[1]ICRU: International Commission on Radiation Units and Measurements

Radiation protection principles

1. Justification

Any exposure of persons to ionising radiation has to be justified

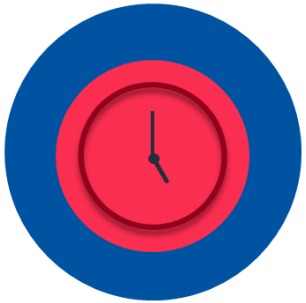
2. Limitation

The personal doses have to be kept below the legal limits

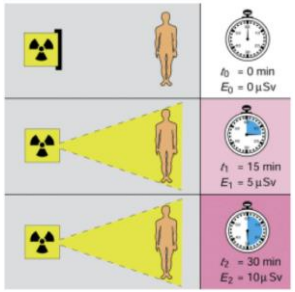
3. Optimisation

The personal and collective doses have to be kept as low as reasonably achievable (ALARA)

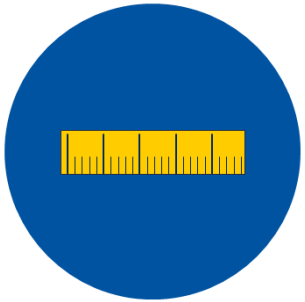
General protective measures



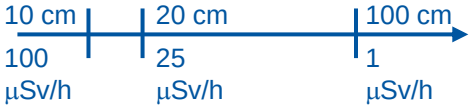
1. REDUCE TIME



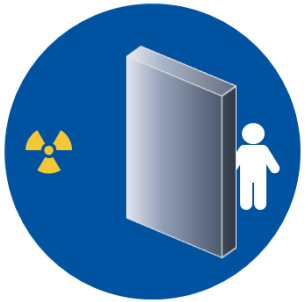
- Dose is proportional to exposition time
  - ➢ Train on mock-ups
  - ➢ Fast connections
  - ➢ Robots



2. KEEP A SAFE DISTANCE

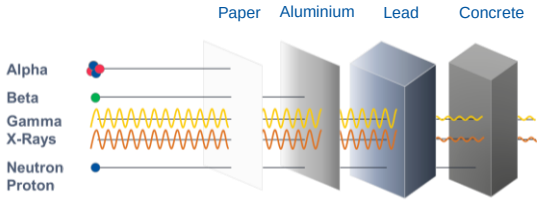


- Keep distance to radioactive source
- For point sources: dose ~ $1/R^2$
  - ➢ Use tools/detectors with extensions



3. USE ADEQUATE SHIELDING

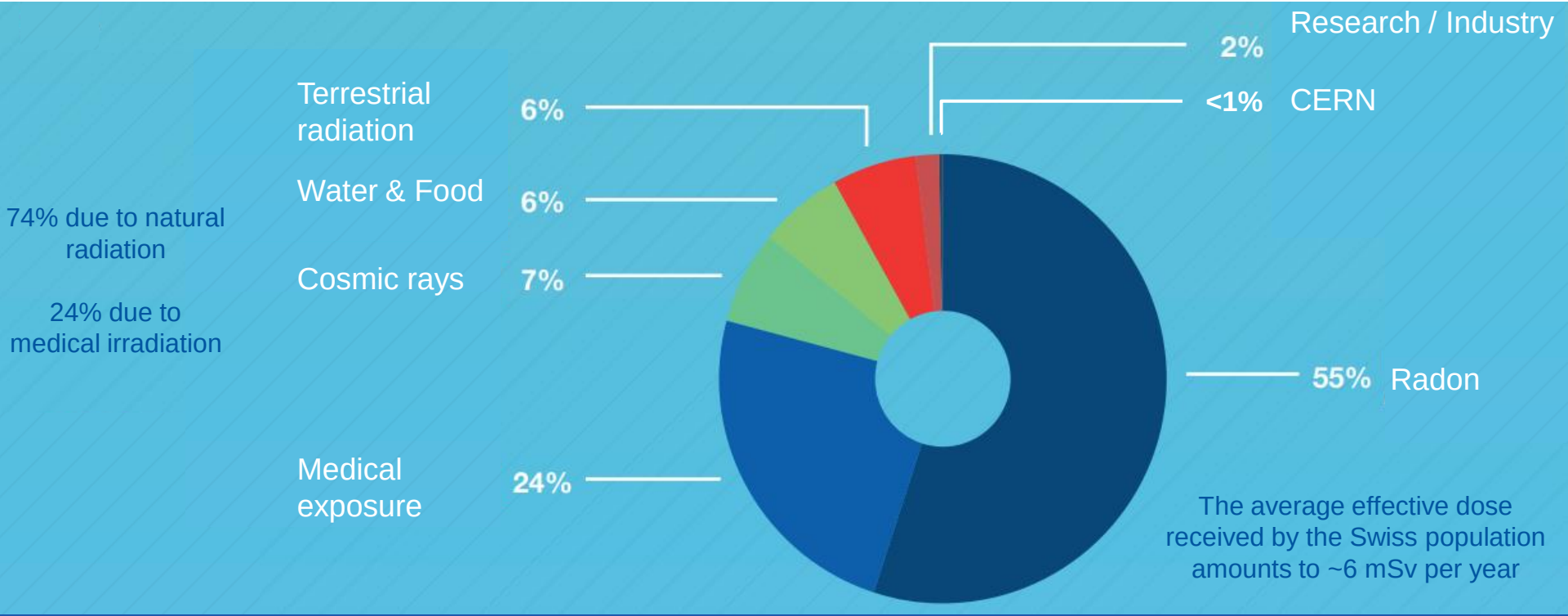
- Use adequate shielding to reduce the dose received



Natural and artificial radiation

74% due to natural radiation

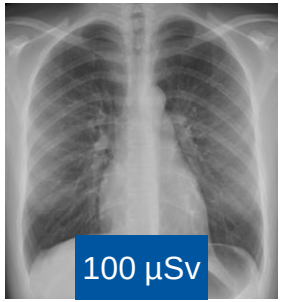
24% due to medical irradiation



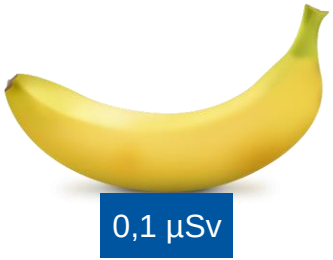
The average effective dose received by the Swiss population amounts to ~6 mSv per year

Dose game

Foot X-ray

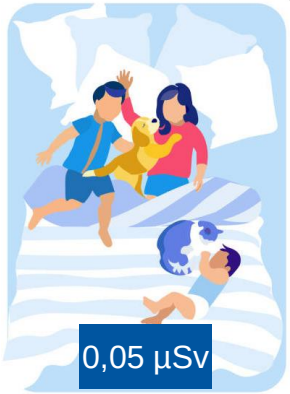


Chest X-ray



Eating 1 banana

1 year in Switzerland

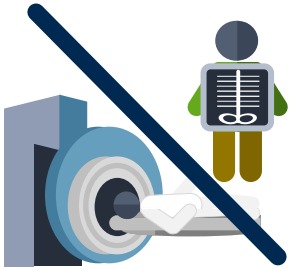


Sleeping next to someone

1 week in the mountains

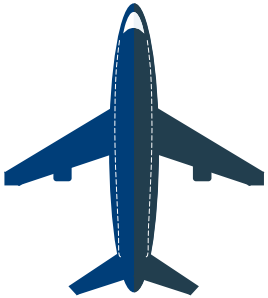
1 day in space

1 flight Geneva-LA



1.4 mSv
(annual)

Average dose through medical exposure (Switzerland)



3 mSv
(annual)

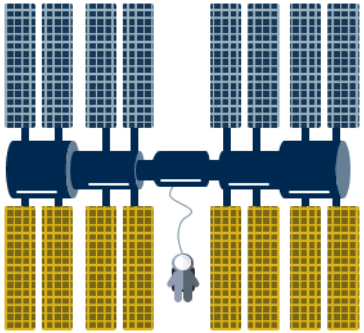
Average dose for aeroplane pilots

~ 4 mSv
(annual)

Natural background radiation in Switzerland

20 mSv
(annual)

Maximum dose for a radiation worker



146 mSv
(annual)

Dose for crew members of the International Space Station

Dose

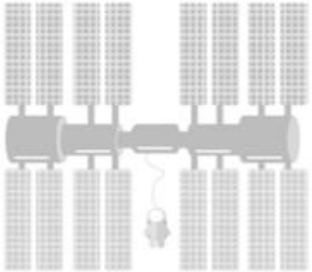
< 1 mSv
(annual)

1.4 mSv
(annual)

3 mSv
(annual)

~ 4 mSv
(annual)

20 mSv
(annual)



50 - 100 mSv
(annual)

10 Sv

Dose

Yearly dose of 99.98% of CERN personnel in 2020

Average dose through medical exposure (Switzerland)

Average dose for airplane pilots

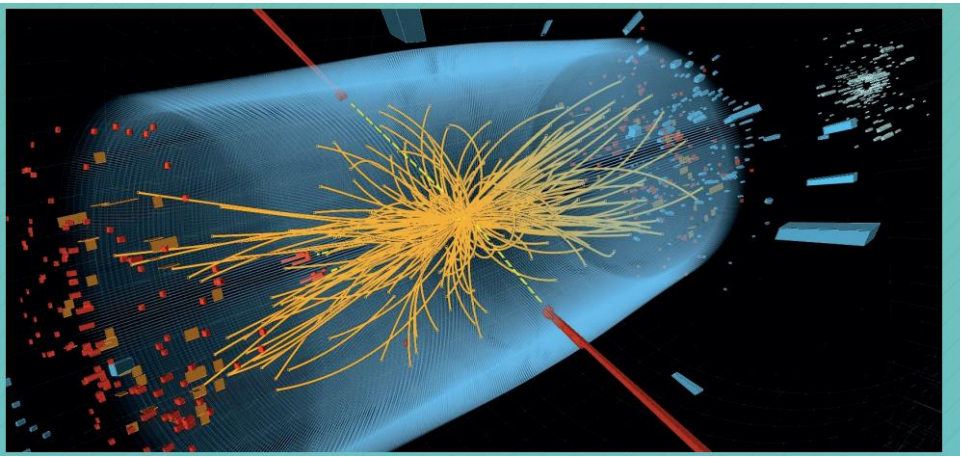
Natural background Radiation in Switzerland

Maximum dose for a nuclear worker

Dose for crew members of International Space Station

Lethal dose 100

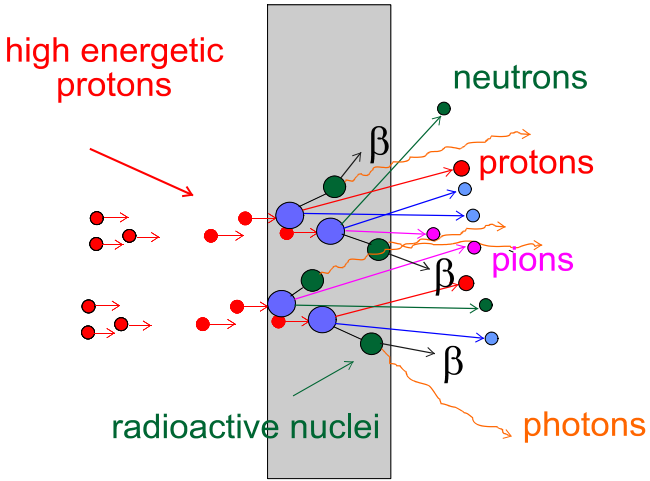
Radiation at CERN



High-energy particle beams can generate secondary particles when they hit matter. The particles form so-called stray radiation when the accelerator is in operation. ***Stray radiation*** *ceases when the accelerator is not running*

Radiation fields at accelerators

Prompt radiation – Accelerator in operation



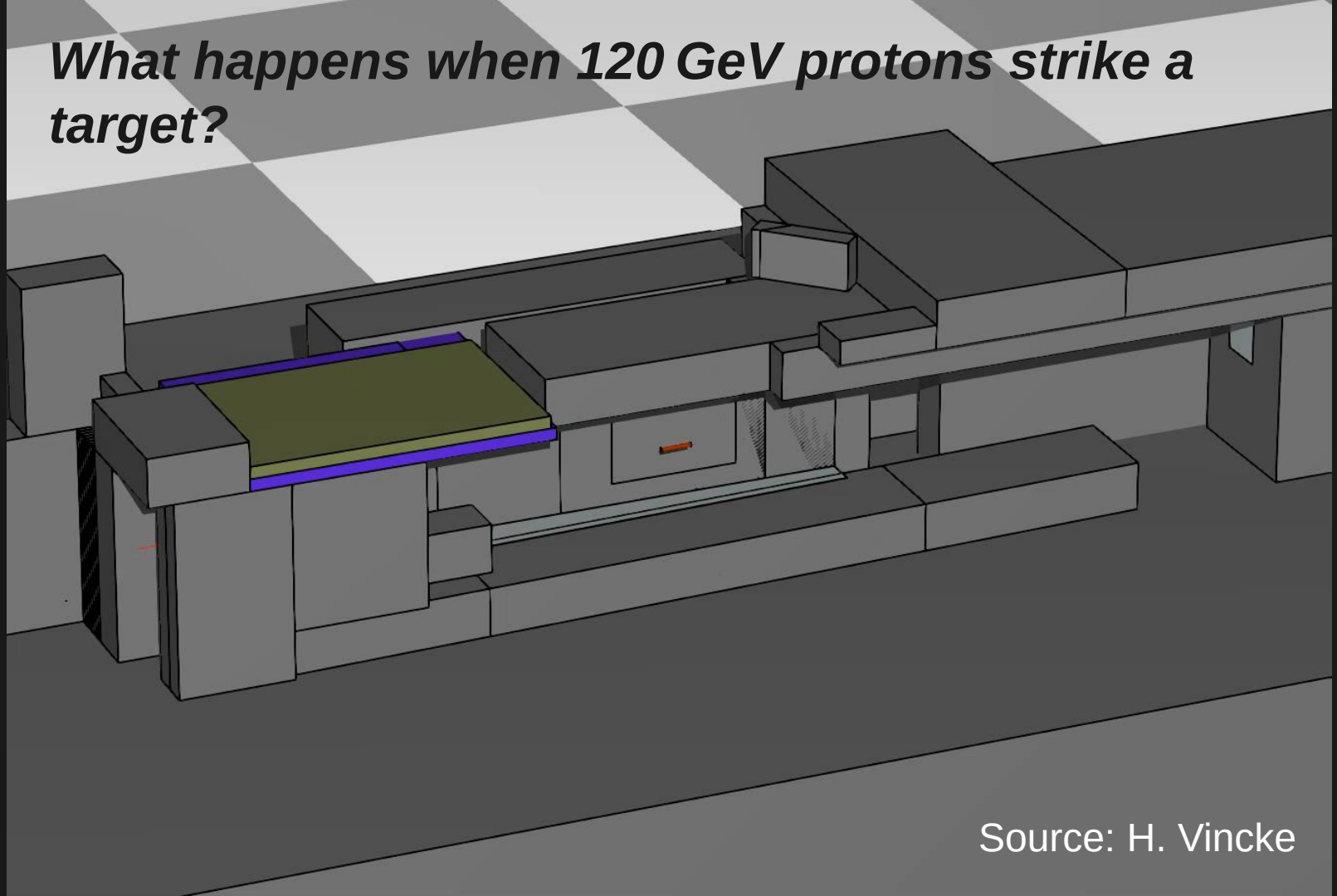
Source: H. Vincke

A whole zoo of particles with energies reaching up to the original beam energy

High pressure ionization chamber

REM detector

What happens when 120 GeV protons strike a target?



Source: H. Vincke

Activation

At high-energy accelerators, primary or secondary particles interact with surrounding matter. Through interactions with atomic nuclei, radioactive isotopes can be produced. The main production channels for activation in such cases are:

Disintegration processes, e.g. spallation reactions, (n,2n), (n,p), (n,alpha), ...

Particle capture (mainly neutrons)

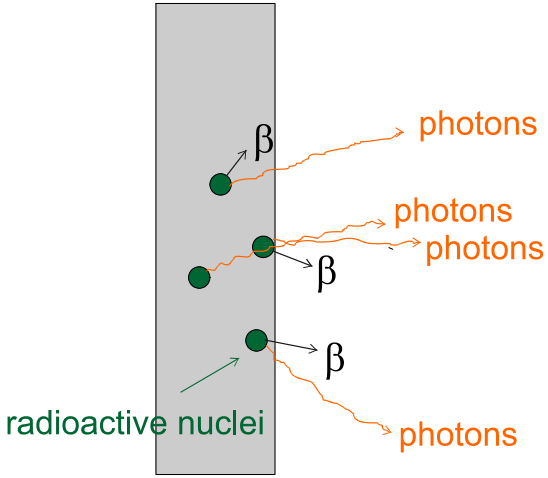
(γ,n)-reactions

Animations: H. Vincke

- **Impacts:**
  Experiments, accelerators, and their surroundings can become radioactive and contribute to radiation exposure for personnel and the environment
- ***Mitigation measures:***
  - *Reduce beam losses*
  - *Optimize material selection*
  - *Provide adequate shielding*
  - *…*

Radiation fields at accelerators

Radiation due to activation – Accelerator not in operation



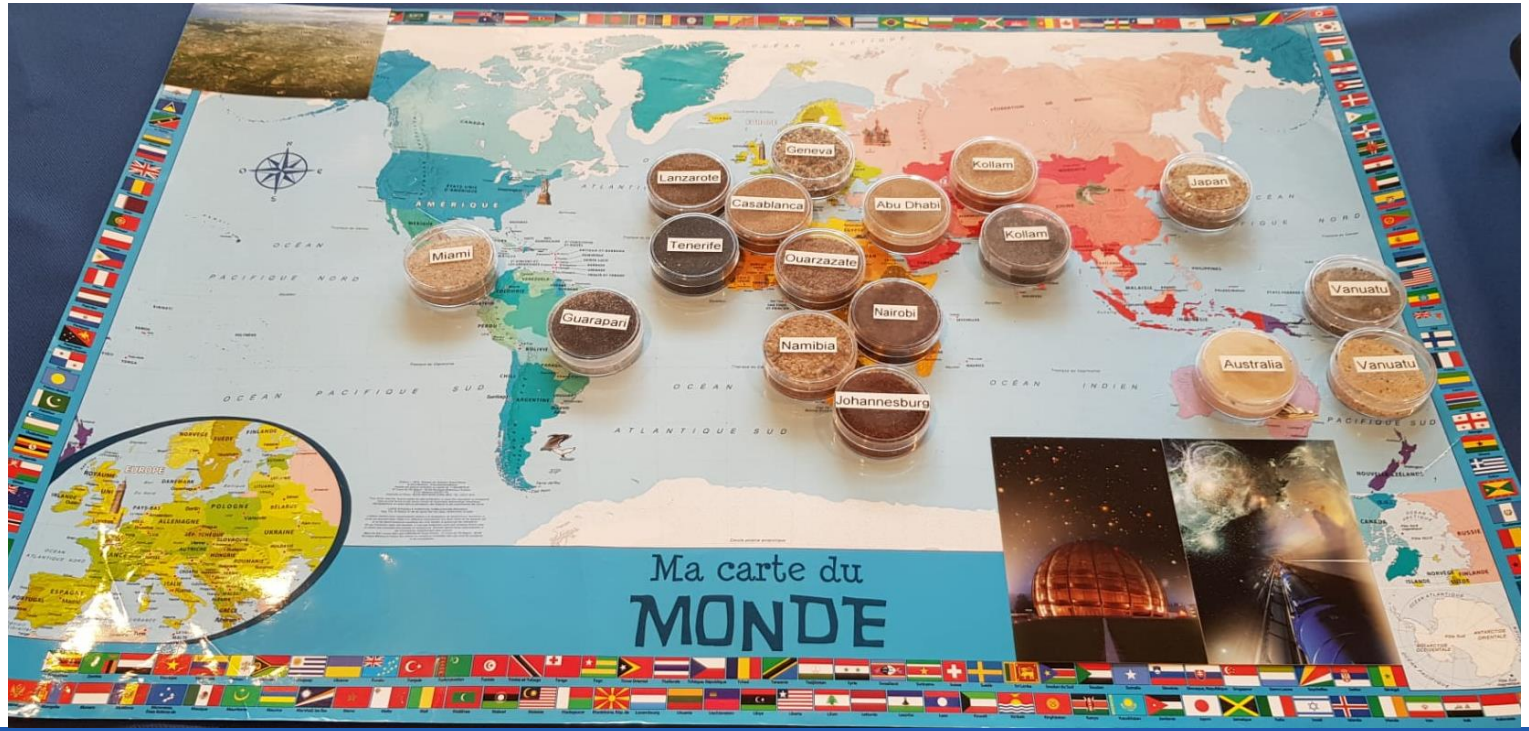
Source: H. Vincke

α, β-, γ-radiation, primarily γ of energies < 2.76 MeV

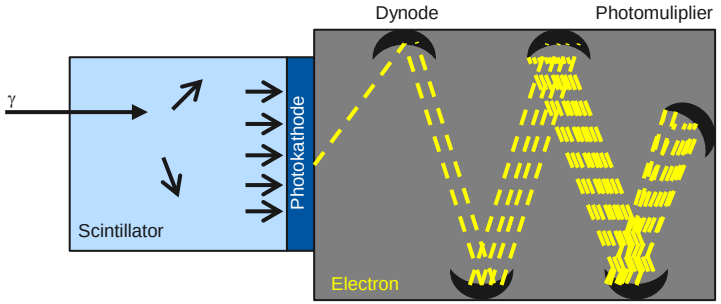
Air filled ionization chamber

Portable devices - AD6 (Geiger-Mueller counter)

Measureing natural radioactivity



Scintillation detector

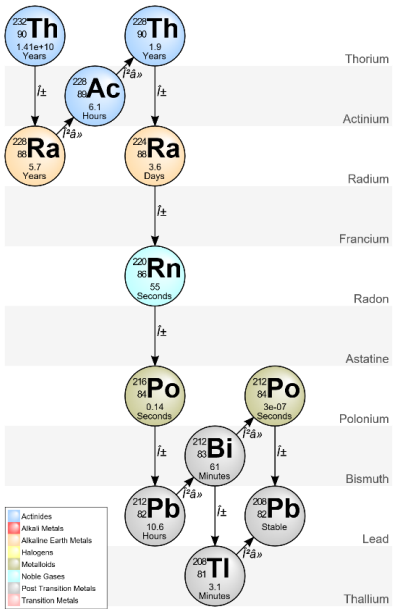


- **Photon-matter interactions**:
  - Photoelectric effect
  - Compton effect
  - Pair production

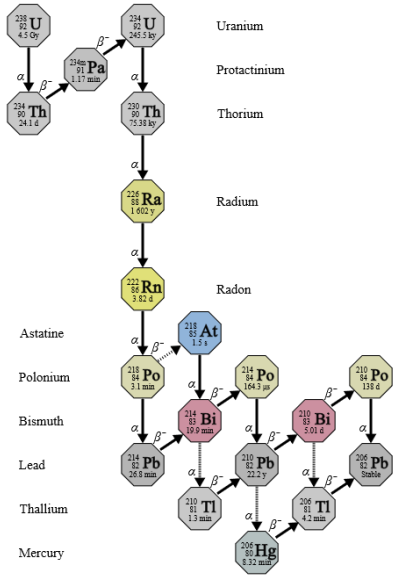
- Gamma radiation strikes the **scintillator**, which converts the incoming radiation into **visible light photons**
- These photons hit the **photocathode**, which emits electrons due to the **photoelectric effect**
- The photomultiplier tube contains several **dynodes**, each at an increasingly higher potential. When the emitted electrons strike these dynodes, additional electrons are released at each stage, amplifying the signal
- The **multiplied electrons** then reach the **anode**, where an electrical signal is generated. This signal is proportional to the original light signal
- The resulting electrical signal can then be used for various measurements, such as radiation detection

Main decay chains in nature

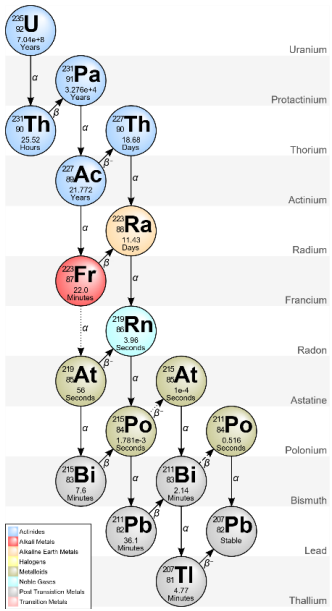
Thorium series

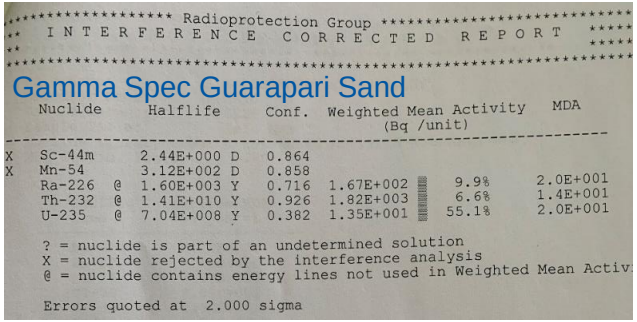


Uranium series



Actinium series





Radioprotection Group

INTERFERENCE CORRECTED REPORT

Gamma Spec Guarapari Sand

	Nuclide		Halflife		Conf.	Weighted Mean Activity (Bq /unit)		MDA
X	Sc-44m		2.44E+000	D	0.864			
X	Mn-54		3.12E+002	D	0.858			
	Ra-226	@	1.60E+003	Y	0.716	1.67E+002	9.9%	2.0E+001
	Th-232	@	1.41E+010	Y	0.926	1.82E+003	6.6%	1.4E+001
	U-235	@	7.04E+008	Y	0.382	1.35E+001	55.1%	2.0E+001

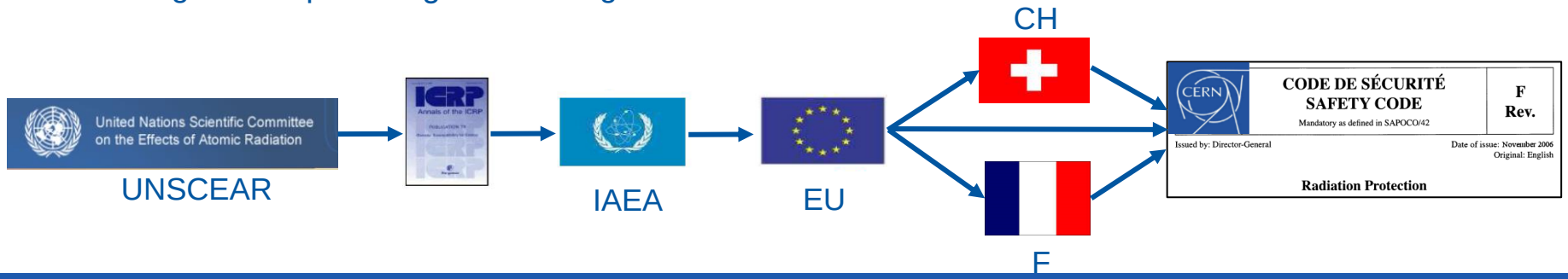
? = nuclide is part of an undetermined solution
X = nuclide rejected by the interference analysis
@ = nuclide contains energy lines not used in Weighted Mean Activ

Errors quoted at 2.000 sigma

- 3 main decay chains are observed in nature, commonly called the **thorium**, **uranium** (radium) and **actinium** series
- The long-lived starting isotopes of these series have existed since the formation of the earth, 4.5 billion years ago (artificial isotopes since 1940s)
- Also, ^{40}K ($t_{1/2}$ =1.25 billion y) is still present
- ^{40}K makes up 0.012% of natural K and is the largest source of natural radioactivity humans (70 kg body contains ~175 g K → 0.02 g ^{40}K, which produces 5390 Bq, bananas include ^{40}K (~450 mg K, ~0.1 uSv per banana))
- Brazil nuts include K-40, Ra-226, and Th-232
- Guarapari (Brazil) sand sample includes Ra-226, Th-232 and U-235

CERN RP Legal Framework

- CERN is an intergovernmental Organization subject not to national but **international law**. Its status has been recognized by its host states where it must ensure their safety and security
- CERN has the right to establish **its own rules** as necessary for the proper functioning of the Organization, among others, **Safety Rules**
- CERN agrees to follow best practices in matters of radiation protection and radiation safety taking into account the legislation of its host states, as well European and international standards. Their implementation is discussed between the host states authorities, ASN (F) and OFSP (CH), and CERN according to a "Tripartite Agreement" signed in 2010



Radiation protection principles

1. Justification

Any exposure of persons to ionising radiation has to be justified

2. Limitation

The personal doses have to be kept below the legal limits

3. Optimisation

The personal and collective doses have to be kept as low as reasonably achievable (ALARA)

Limitation – Safety Code F

Occupationally exposed persons (Radiation Workers)

3.2.1 The effective dose received in any consecutive 12-month period by any occupationally exposed person must not exceed 20 mSv.

3.4.1 All occupationally exposed persons are classified in one of two categories:

a) Category A: persons who may be exposed in the exercise of their profession to more than 3/10 of the limit in terms of effective dose in 12 consecutive months.

b) Category B: persons who may be exposed in the exercise of their profession to less than 3/10 of the limit in terms of effective dose in 12 consecutive months.

Category A: **20 mSv / year (*)**

Category B: **6 mSv / year (*)**

(*) Apprentices and students (age 16-18 yrs): 6 mSv/year

Pregnant persons: 1mSv/year

Not occupationally exposed persons

3.2.3 The effective dose received in any consecutive 12-month period by persons not occupationally exposed must not exceed 1 mSv.

1 mSv / year

Environment (Public)

4.2.1 The effective dose resulting from CERN's activities received by any person living or working outside the site boundaries must not exceed 0.3 mSv per year. This limit includes both external and internal exposure, the latter resulting from the intake of radioactive releases.

0.3 mSv / year

Limitation – Area Classification

External exposure

	Area	Annual dose limit (year)	Ambient dose equivalent rate		Sign
			permanent occupancy	low occupancy	
	Non-designated	1 mSv	0.5 µSv/h	2.5 µSv/h	
Radiation Area	Supervised	6 mSv	3 µSv/h	15 µSv/h	
	Simple Controlled	20 mSv	10 µSv/h	50 µSv/h	
	Limited Stay	20 mSv	-	2 mSv/h	
	High Radiation	20 mSv	-	100 mSv/h	
	Prohibited	20 mSv	-	> 100 mSv/h	
Controlled Area					

Total number of working hours per year: 2000 hrs

Example:
Supervised Area 3 µSv/h × 2000 hrs = 6 mSv

Low-occupancy: < 20% of working time

Limitation – Area Classification

Internal exposure

CS, CA: Nuclide-specific Guidance values
from Swiss legislation

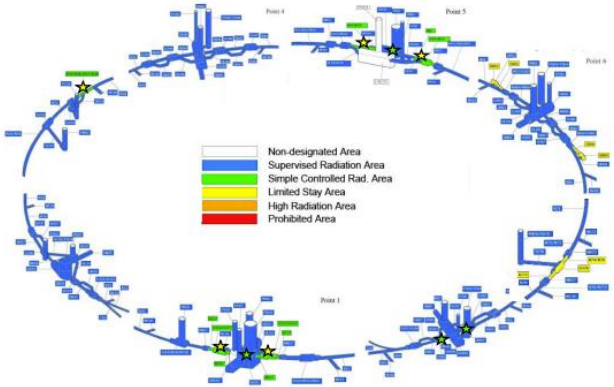
Specific airborne radioactivity
1 CA = effective committed dose of 20 mSv for a stay of 2000 hours/year

Specific surface contamination
1 CS = 1/10th of dose limit to skin and/or 0.5 mSv/year for daily ingestion of contamination on 10 cm^2

"No contamination"
< 1 CS for identified isotopes
< 1 Bq/cm^2 for non-identified gamma and beta emitters
< 0.1 Bq/cm^2 for non-identified alpha emitters

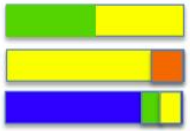
	Area	Annual dose limit (year)	Specific airborne radioactivity	Specific surface contamination
	Non-designated	1 mSv	0.05 CA	1 CS
Radiation Area	Supervised	6 mSv	0.1 CA	1 CS
	Simple Controlled	20 mSv	0.1 CA	1 CS
	Limited Stay	20 mSv	100 CA	4000 CS
	High Radiation	20 mSv	1000 CA	40000 CS
	Prohibited	20 mSv	> 1000 CA	> 40000 CS

Area classification in 2013



Non-designated Area
Supervised Radiation Area
Simple Controlled Rad. Area
Limited Stay Area
High Radiation Area
Prohibited Area

- 45 km of radiation areas:
  - ❑ LINACs
  - ❑ PSB-PS-SPS (~ 15 km)
  - ❑ LHC (27 km)



- 5 Target Areas

- Experimental areas

- LHC experiments

- RIB facility ISOLDE – Class A and C labs
- n-TOF – Class A

Radiation protection principles

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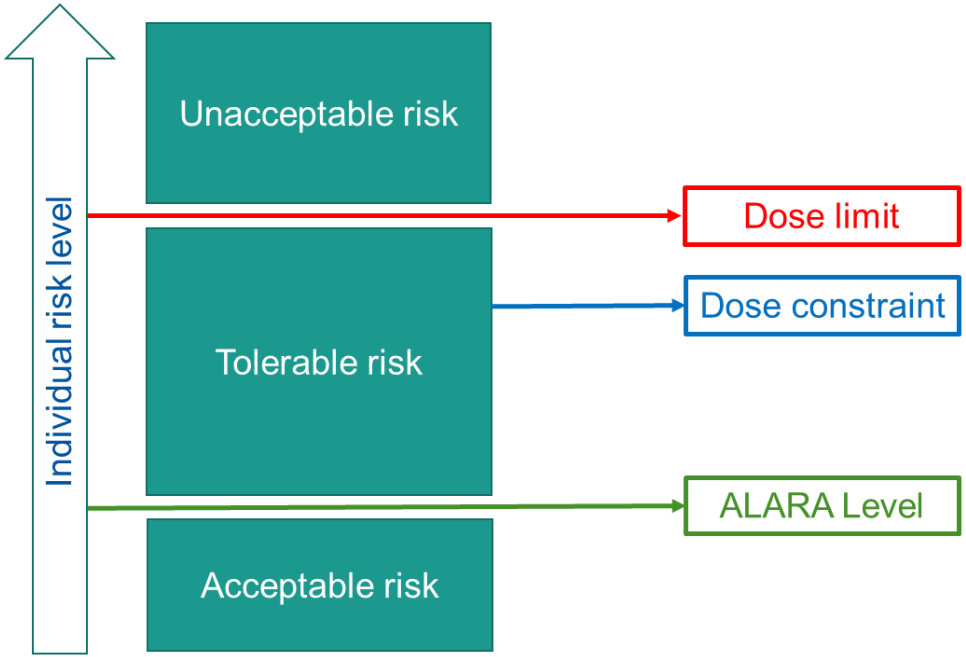
Dose Optimization at CERN



	CERN workers		Population
	Radiation Workers	Other Workers	
Dose limit	20 mSv/yr*	1 mSv/yr	300 µSv/yr
Dose constraint	3 mSv/yr	100 µSv/yr	10 µSv/yr
	Optimization process		
ALARA Level	100 µSv/yr	10 µSv/yr	10 µSv/yr

* Apprentices and students (age 16-18): 6 mSv/yr
Pregnant women: 1mSv/yr

ALARA Criteria and Levels

Optimization is legal requirement if accumulated dose exceeds 100 µSv (ALARA)
Optimization includes different areas/aspects: work coordination, work procedures, handling tools, design, material choices

Group 1 criteria define the ALARA level

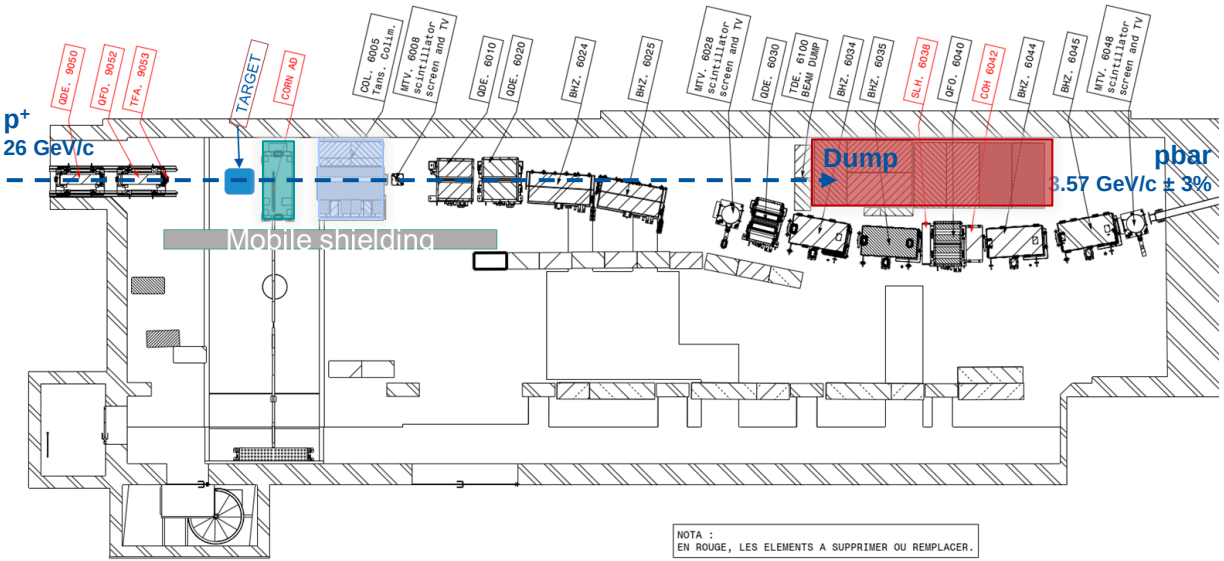
ALARA Comittee

Individual dose equi.	**Level I**	100 µSv	**Level II**	1 mSv	**Level III**
Collective dose equi.		500 µSv		5 mSv	

Group 2 criteria are the bases of **a radiological risk assessment** (including accidents and incident scenarios) by the RSO and HSE-RP prior to the final ALARA level classification of the intervention.

Ambient dose equivalent rate	**Level I**	50 µSv/hr	**Level II**	2 mSv/hr	**Level III**
Airborne activity in CA		5 CA		200 CA	
Surface contamination in CS		10 CS		100 CS	

CERN AD – Target Area



Target
Production of secondary particles (including antiprotons) due to the nuclear interaction between the proton beam and the iridium target.

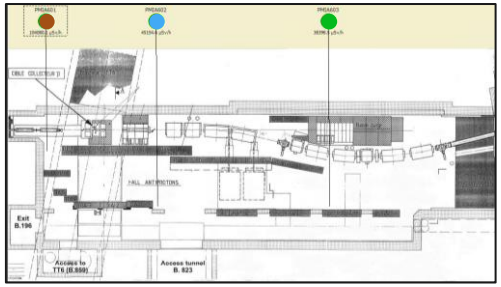
Magnetic Horn
Two coaxial conductors to generate a toroidal magnetic field inside the volume. Focusing/defocusing charged particles in the forward direction.

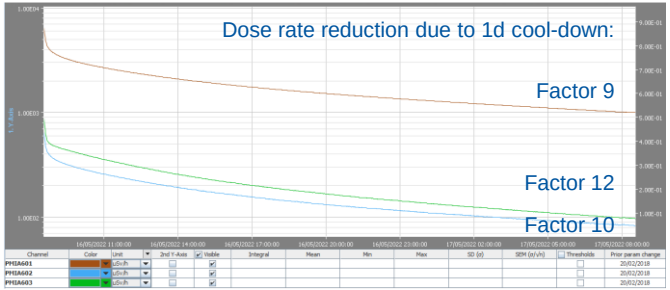
Collimator
Reduction of the secondary shower toward the AD hall and protection of the downstream machine equipment.

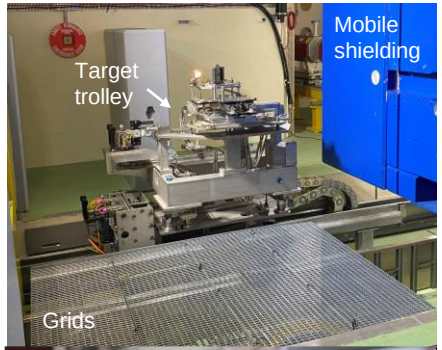
Dump
Absorbs the uncollided or elastically scattered primary proton beam from the PS.

Magnetic „dog-leg“
Composed by a set of bending dipoles and quadrupoles. Momentum cut of 3.57 GeV/c ± 3% for which the injection into the AD ring is designed.

AD Target Exchange – ALARA L2







- AD Target replacement during a short technical stop
- Very high dose rates near the target, with 60 mSv/h at 40 cm distance after 25 hours → 1 minute = 1 mSv!
- The AD target area was renovated in 2019/2020, introducing a “plug-in” target system for easier handling via robot
- A rehearsal of the target replacement and intensive preparations were carried out in advance
- Mobile shielding and a shielded container were used for the target
- A light protective grid was installed quickly

➢ Maximum individual dose: 40 µSv and collective dose: 156 person·µSv

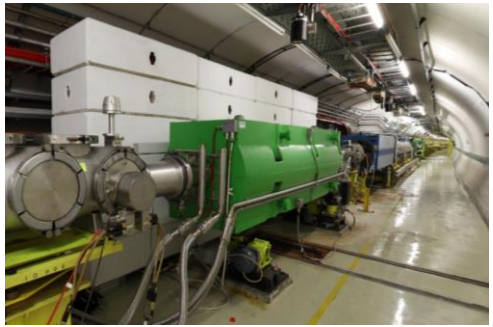
Esample: SPS Beam dump upgrade

Courtesy: Helmut Vincke (CERN, HSE-RP)

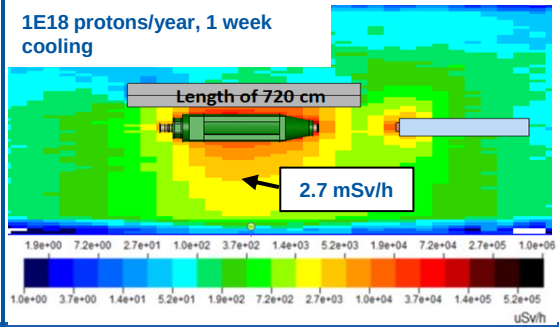
ALARA in the accelerator environment

Until 2018

From a simple beam stopper in SPS LSS1…



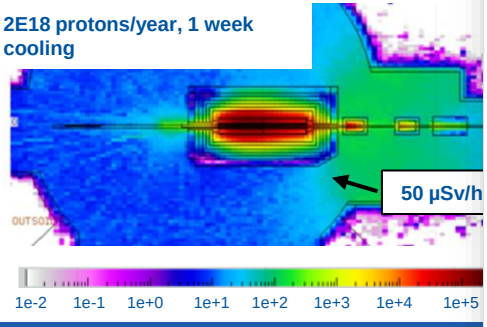
1E18 protons/year, 1 week cooling



Since 2021

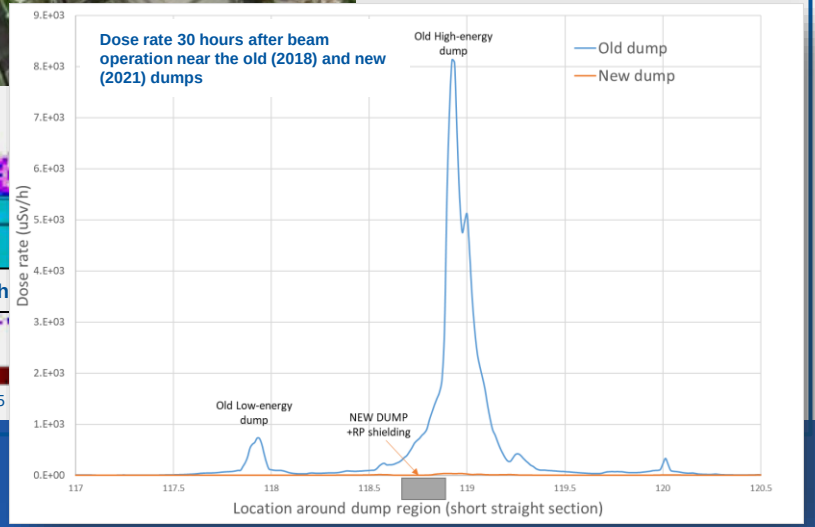
… into a fully RP-optimized, heavily shielded dump in SPS LSS5

2E18 protons/year, 1 week cooling



Significant reduction in residual dose rate and air activation

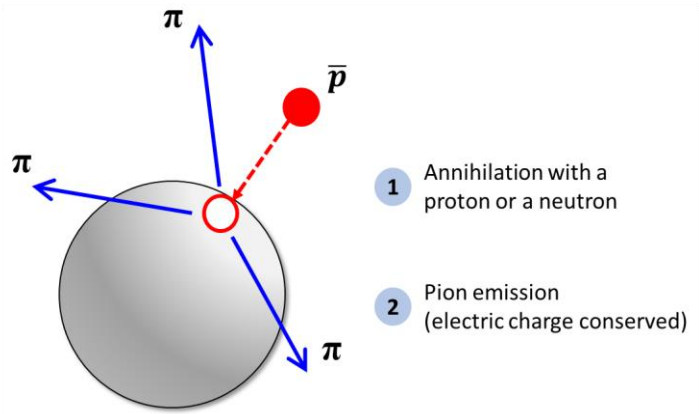
No radiation damage to equipment near the dump

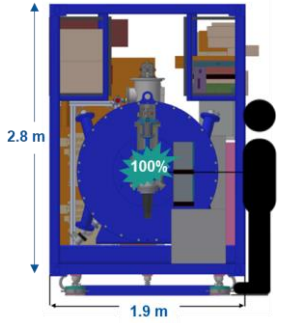


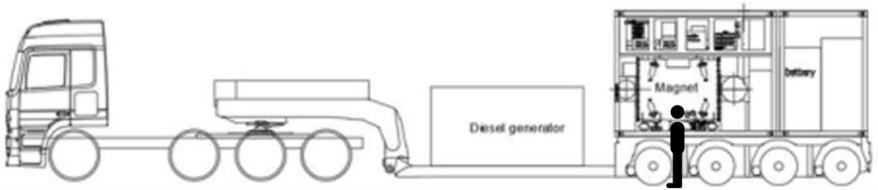
ALARA im Design von Experimenten

- PUMA (antiProton Unstable Matter Annihilation) is an approved nuclear-physics experiment at CERN
- It aims at characterizing the neutron-to-proton content of the nuclear density tail of **stable** and **unstable nuclei** from **antiproton-nucleus annihilations**
- The emitted particles shall be measured allowing to characterize the surface properties of the nuclei
- Today, no facility worldwide provides low-energy antiprotons to be used as probes for unstable nuclei

➢ PUMA therefore aims at trapping antiprotons and transporting them from AD/ELENA to ISOLDE







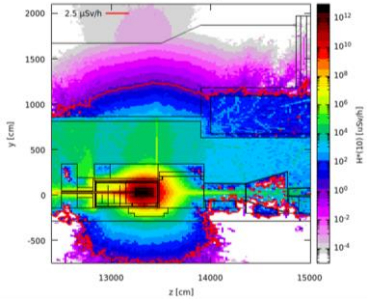
➢ During a transport of 10^9 antiprotons an accidental dose of only **15 µSv** could be reached in the worst case

ALARA for the design of experiments

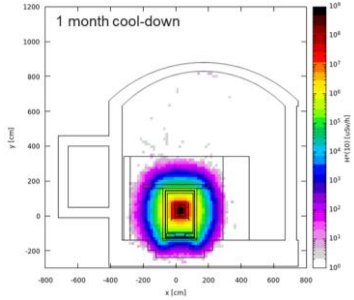
Design of a new facility at the SPS for the SHiP experiment, which searches for dark matter

BBC Article: CERN Scientists search for mysterious ghost particles

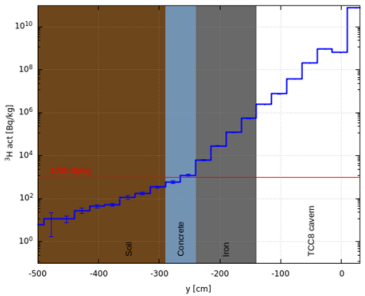
Prompt Radiation

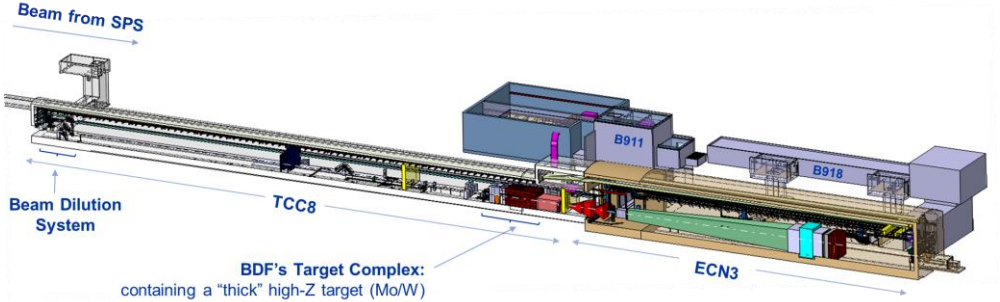


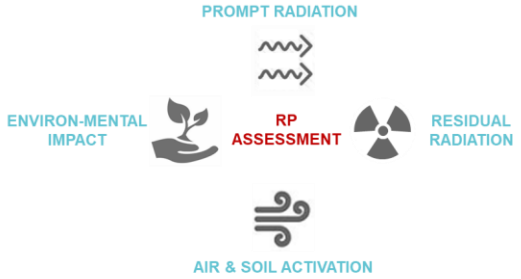
Residual Radiation



H-3 Production







Radiation Protection Group

Mandate

"The Radiation Protection Group (HSE-RP) of the HSE Unit ensures that personnel on the CERN sites and the public are protected from potentially harmful effects of ionizing radiation linked to CERN activities. The HSE-RP Group fulfils its mandate in collaboration with the CERN departments owning or operating sources of ionizing radiation and having the responsibility for Radiation Safety of these sources."

Operational Radiation Protection

- Risk assessments for personnel and public
- Definition of protective measures, authorization of operation
- Lead in implementation of ALARA principle
- Studies for projects and upgrades
- R&D for tools and methods, operation of shielding benchmark facility

Environmental Radiation Protection

- Environmental monitoring program and studies of environmental impact for upgrades and new facilities

Radioactive Waste Management

- Operation of pre-conditioning and interim storage facility
- Waste disposal towards host states
- Support to Departments in radioactive waste minimization and treatment

Individual Dosimetry

- Monitoring of external and internal doses and reporting (CERN dosimetry service carries official accreditation in Switzerland)
- Operation of calibration facility

Instrumentation

- Development, installation and operation of radiation monitoring system

Services

- Inter/intra-site radioactive transport
- Shipping (import/export) of radioactive goods
- Radiological characterization of material and waste, operation of analytical laboratory
- Radioactive sources service

Dosimetry

Annual dose distribution

Dose interval (mSv)	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023 until Oct
0	6273	7616	8704	8788	9034	9824	8462	6272	6904	7626	7735
0.1-0.9	2188	1816	1108	1003	1110	1260	1494	799	804	771	624
1.0-1.9	82	133	2	11	3	10	13	17	19	7	4
2.0-2.9	3	14	0	0	0	0	0	0	0	0	0
3.0-3.9	0	1	0	0	0	0	0	0	0	0	0
4.0-4.9	0	0	0	0	0	0	0	0	0	0	0
5.0-5.9	0	0	0	0	0	0	0	0	0	0	0
> 6.0	0	0	0	0	0	0	0	0	0	0	0
Collective dose (mSv) gamma	687	755	214	215	219	232	275	192	187	154	134
Collective dose (mSv) neutron	0	0	0	0	0	0	0	0	0	0	0
Total number of persons	8546	9580	9814	9802	10147	11094	9969	7088	7727	8404	8363

- Maximum annual individual dose in 2023: 1.4 mSv (until 31st of October)

Thank you for your attention