Radiation Protection at High Energy Accelerator Laboratories

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Definition of Radiation Protection

Radiation protection: The protection of people from the effects of ionizing radiation, and the means for achieving this.

- Radiation Protection Training
- Assessment of radiological risks at work places
- Area monitoring
- Individual monitoring of personnel
- Control and characterization of radioactive material and waste
- Management of radioactive sources and waste
- Assessment of radiological risks related to new projects
- …

At CERN: Responsibility of **CERN's Radiation Protection Unit,** providing expert advice, authorizing activities and controlling compliance of activities with RP rules.

Definition of Radiation Safety

Radiation safety: The achievement of proper operating conditions, preventions of accidents or mitigation of accident consequences, resulting in protection of workers, the public and the environment from undue radiation hazards.

- shielding
- beam operation
- access system
- fire prevention
- ventilation
- optimized design of facility
- …

Responsibility of **the owner of the source** emitting ionizing radiation
(At CERN: Departments BE, PH, EN, TE)

www.bfs.de

Ionising Radiation

Ionising radiation are

- photons (X-rays, γ-radiation)
- particles (α-, β- (e^+, e^-), p^+,p^-,n, π^+, π^-, μ^+, μ^-...)

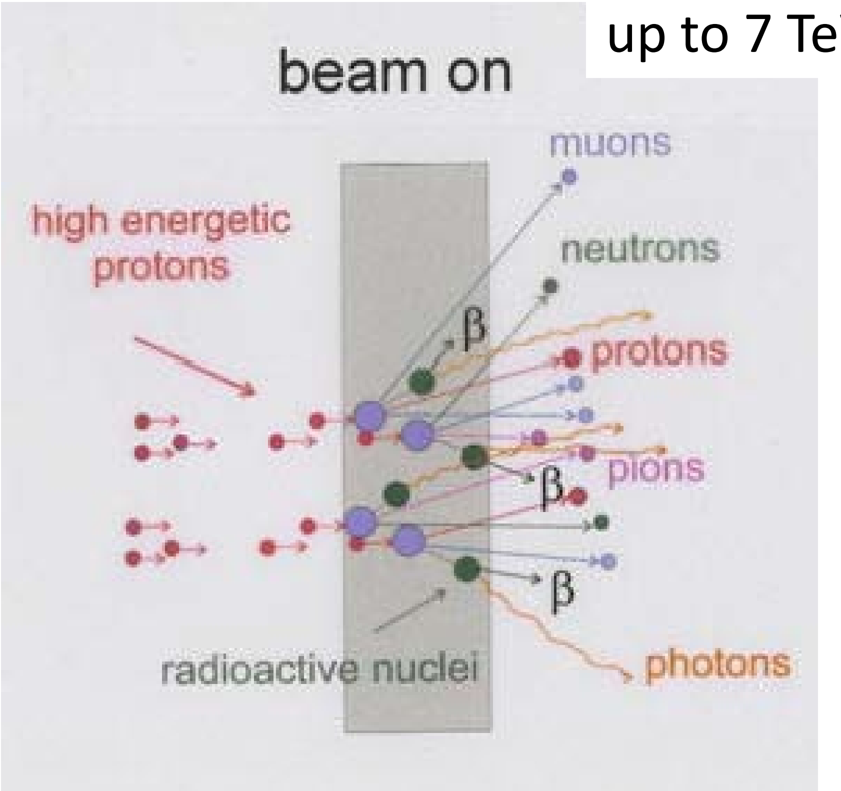
transporting sufficient energy to ionise directly and indirectly atoms and molecules

The interaction between ionising radiation and matter results in an energy absorption and a subsequent potential radiation damage of matter.

Ionising radiation is part of the nature and of human activities in medicine, research, industry, energy production and military

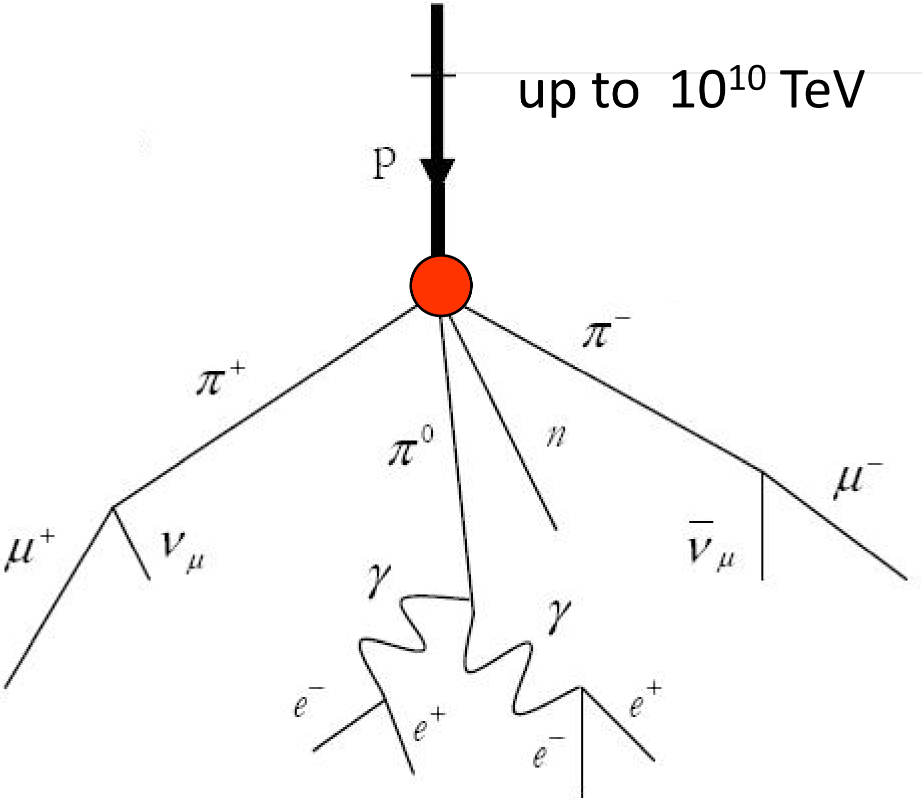
Prompt Ionising Radiation

up to 7 TeV



hadron accelerator

up to 10^{10} TeV



cosmos

high energy, mixed radiation fields

Radiation Showers

Radiation showers development after impact of **ONE** hadron (120 GeV/c) on a copper target

Hadronic shower only

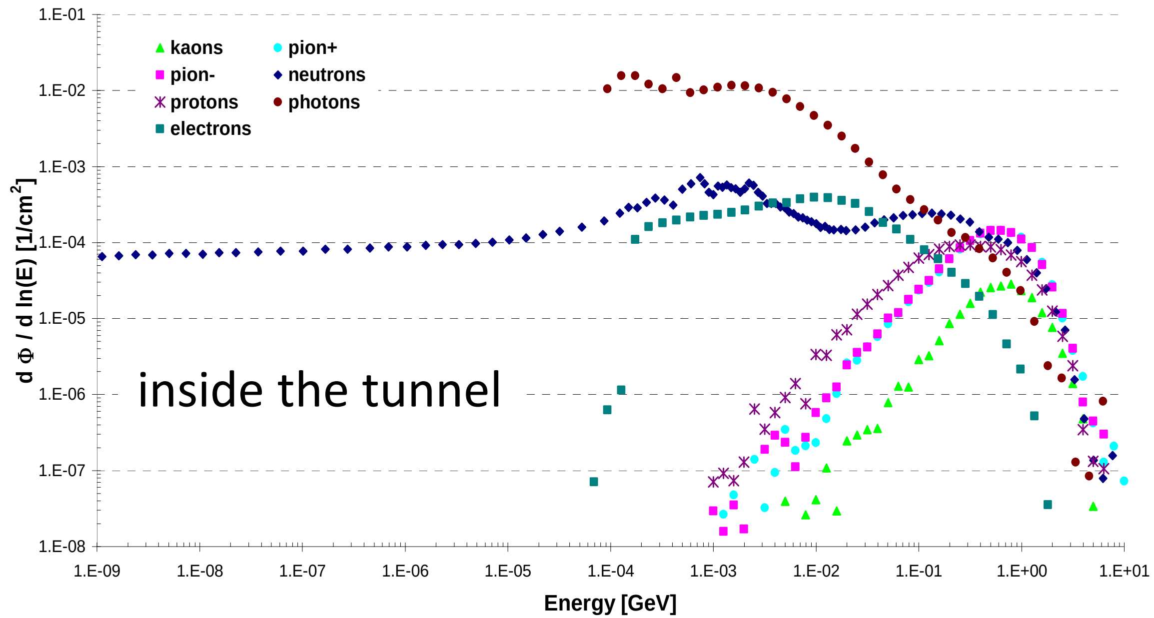
Hadronic shower + photons

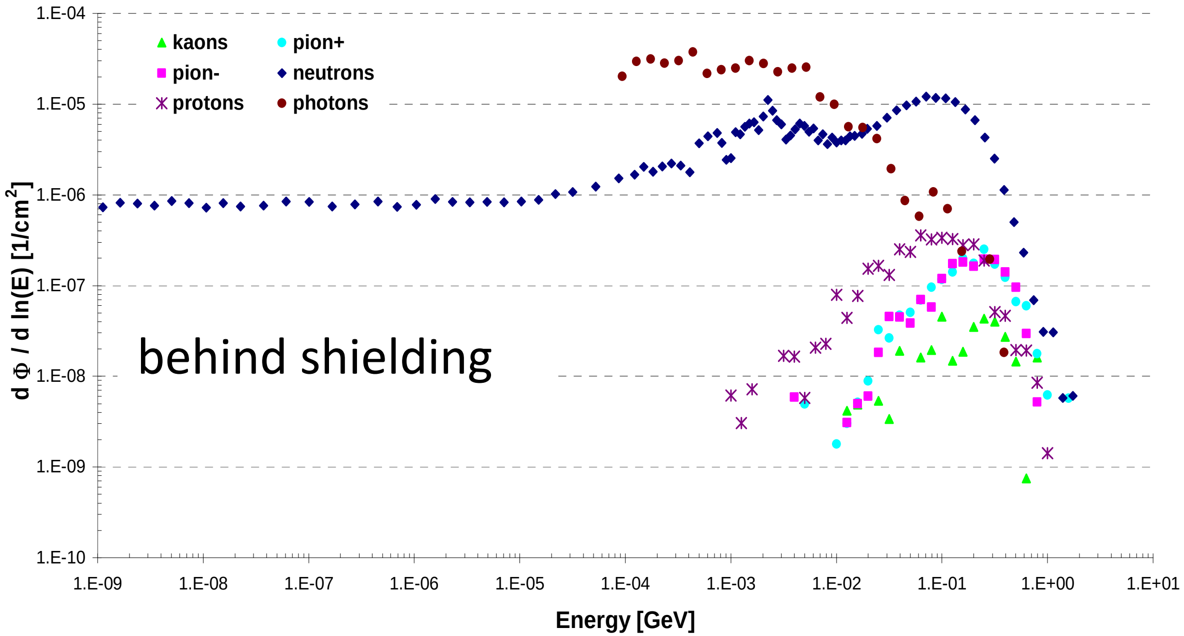
Particle fields (SPS)

Attenuation of radiation H_0 (point source):

$$H = \frac{H_0 * e^{-d/l}}{R^2}$$

d: shielding thickness
R: distance
l: attenuation free path
concrete: l = 40 cm
iron: l= 17 cm





Ambient Dose Equivalent Behind Shielding

	Max. energy	Fraction of ambient dose equivalent
•Neutrons	few GeV	~ 80 %
•Protons	several 100 MeV	~ 20 % (Protons, Charged Pions, Muons, Photons, Electrons + Positrons)
•Charged Pions	"	
•Muons	"	
•Photons	10 MeV	
•Electrons + Positrons	10 MeV	

Ionising Radiation due to Radioactivity

Radioactivity: the phenomenon whereby atoms undergo spontaneous random disintegration, usually accompanied by the emission of ionising radiation. The rate at which this nuclear transformations occurs in matter containing radionuclides is called **activity**. The equation is

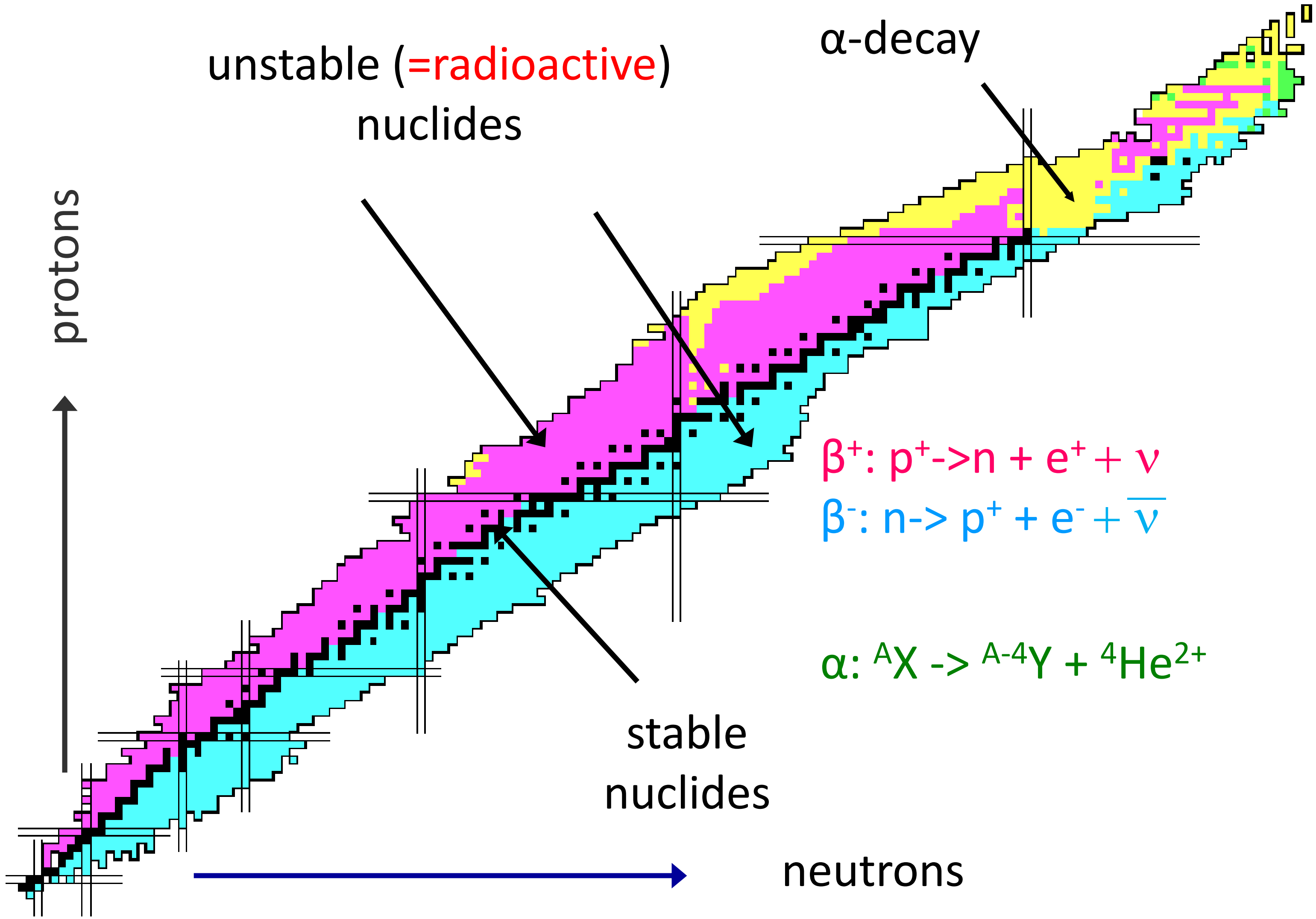
$$A(t) = -dN/dt \; [Bq] \qquad 1\ Bq = s^{-1} \qquad [1\ Ci = 3.7 \times 10^{10}\ Bq]$$

where N is the number of nuclei of the radionuclide, and hence the rate of change of N with time is negative.

The radioactive **half-life** of a radionuclide is the time necessary for half of the nuclei present in the sample to decay

Radionuclides are either natural occurring or produced by nuclear reactions (artificial radionuclides).

Chart of Nuclei



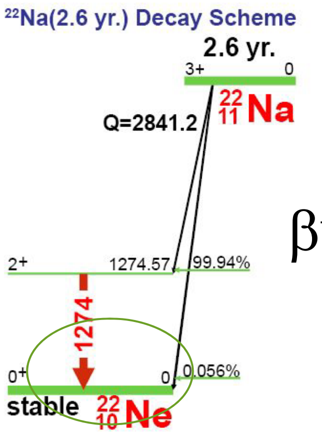
β^+: $p^+ \to n + e^+ + \nu$

β^-: $n \to p^+ + e^- + \overline{\nu}$

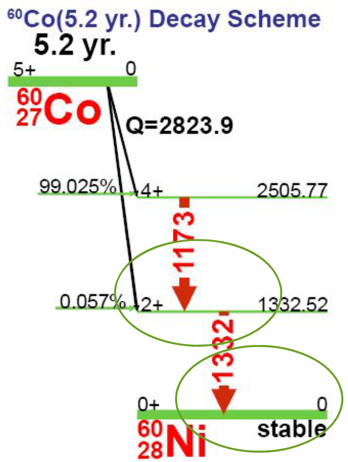
α: $^{A}X \to {}^{A-4}Y + {}^{4}He^{2+}$

Radioactivity

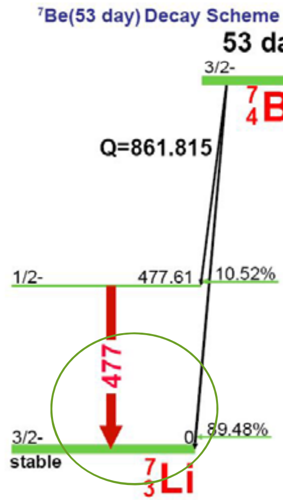
β-, γ-emitter:



β+

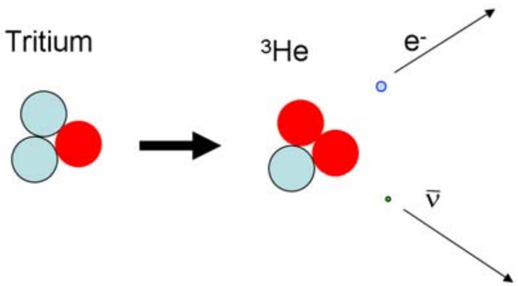


β−



e

pure β-emitter:



α-, β- and γ are emitted with end energies up to few MeV

Terrestrial Radionuclides

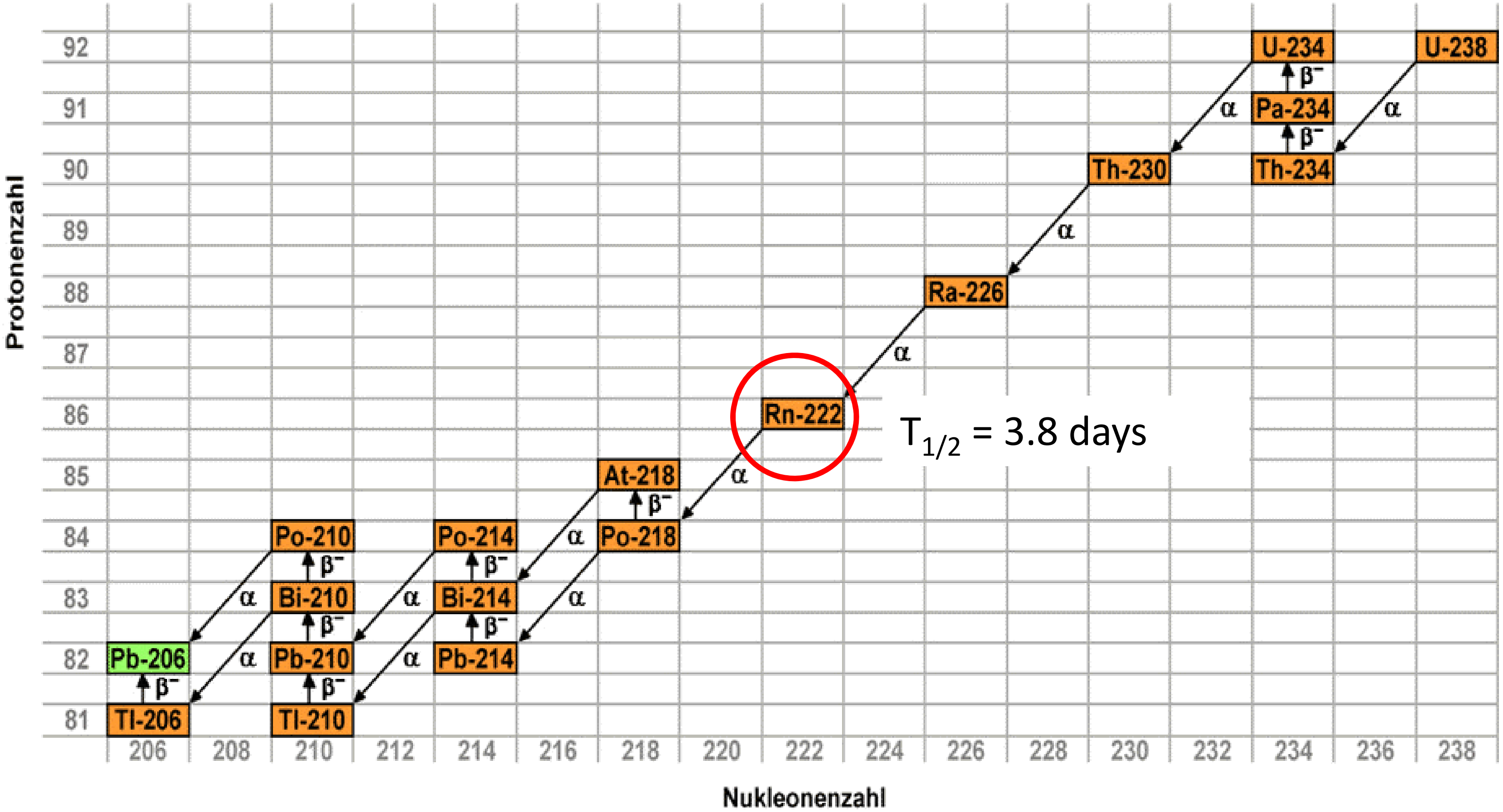
During the creation of the earth, terrestrial nuclides had been incorporated into the earth crust ($T_{1/2}$ some millions of years)

Nuclide	Symbol	Half-life	
Uranium-235	^{235}U	7.04×10^{8} a	0.72% of natural Uranium
Uranium-238	^{238}U	4.47×10^{9} a	99.3% of natural Uranium
Thorium-232	^{232}Th	1.41×10^{10} a	
Potassium-40	^{40}K	1.28×10^{9} a	Earth: 0.037-1.1 Bq/g

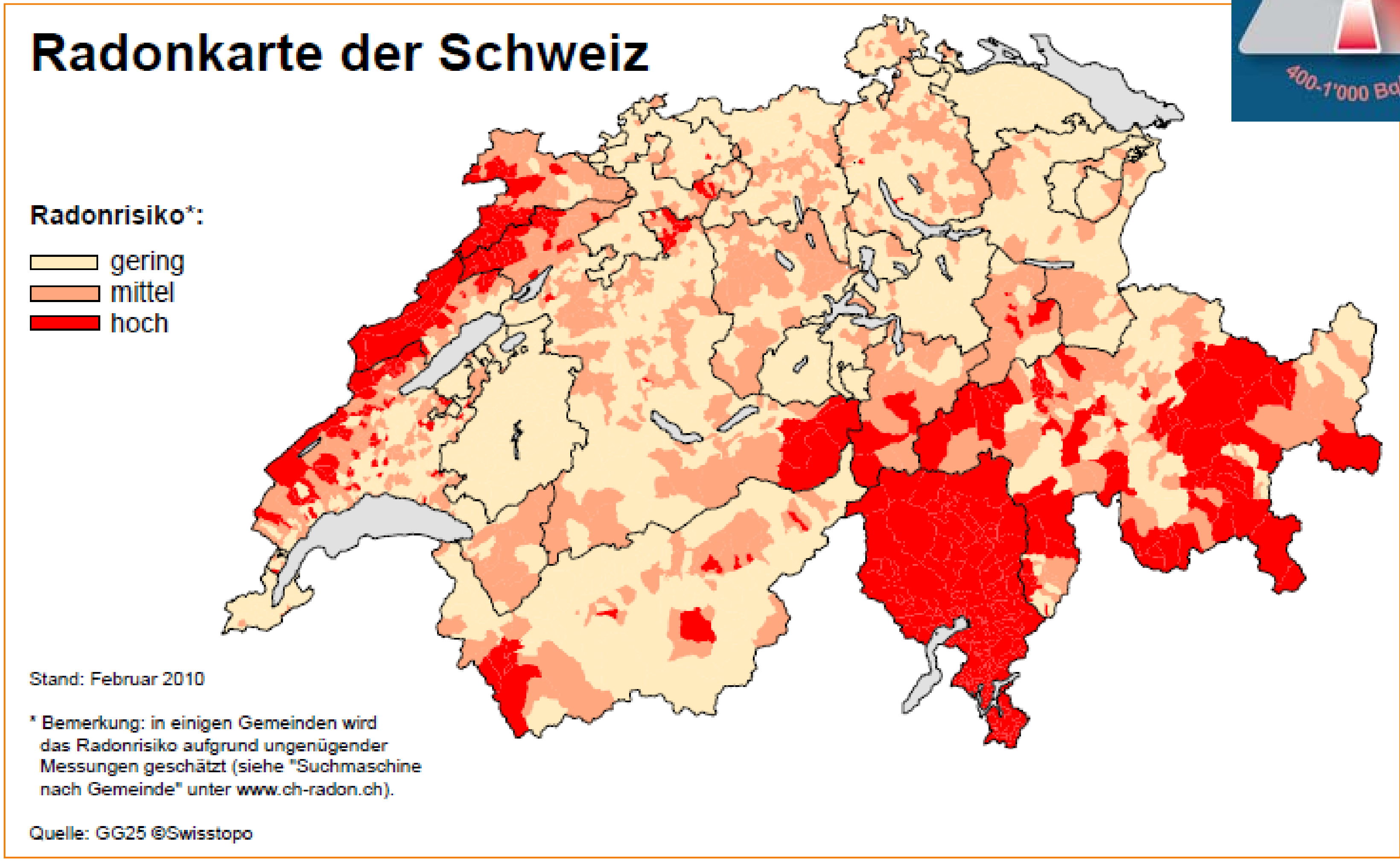
...and some more:

^{50}V, ^{87}Rb, ^{113}Cd, ^{115}In, … ^{190}Pt, ^{192}Pt, ^{209}Bi, …

Uranium-Radium Decay Chain



Radon Map of Switzerland



Cosmogenic Radionuclides

Cosmogenic nuclides are produced by nuclear reaction of cosmic particles with stable nuclei of the atmosphere

Nuclide	Symbol	Half-life	Nuclear Reaction
Carbon-14	^{14}C	5730 a	e.g. $^{14}N(n,p)^{14}C$;
Tritium-3	^{3}H	12.3 a	Interaction of cosmic radiation with N or O; $^{6}Li(n,alpha)^{3}H$
Beryllium-7	^{7}Be	53.28 d	Interaction of cosmic radiation with N or O

More cosmogenic radionuclides:
^{10}Be, ^{26}Al, ^{36}Cl, ^{80}Kr, …

Note: ^{7}Be and Rn decay products are always found in intake filter

...and we find radioactivity in our body

Nuclide	Total activity in human body (~ 70 kg)
Uranium	~ 1 Bq
Thorium	~ 0.1 Bq
Potassium 40	~ 4 - 5 kBq
Radium	~ 1 Bq
Carbon 14	~ 15 kBq
Tritium	~ 20 Bq

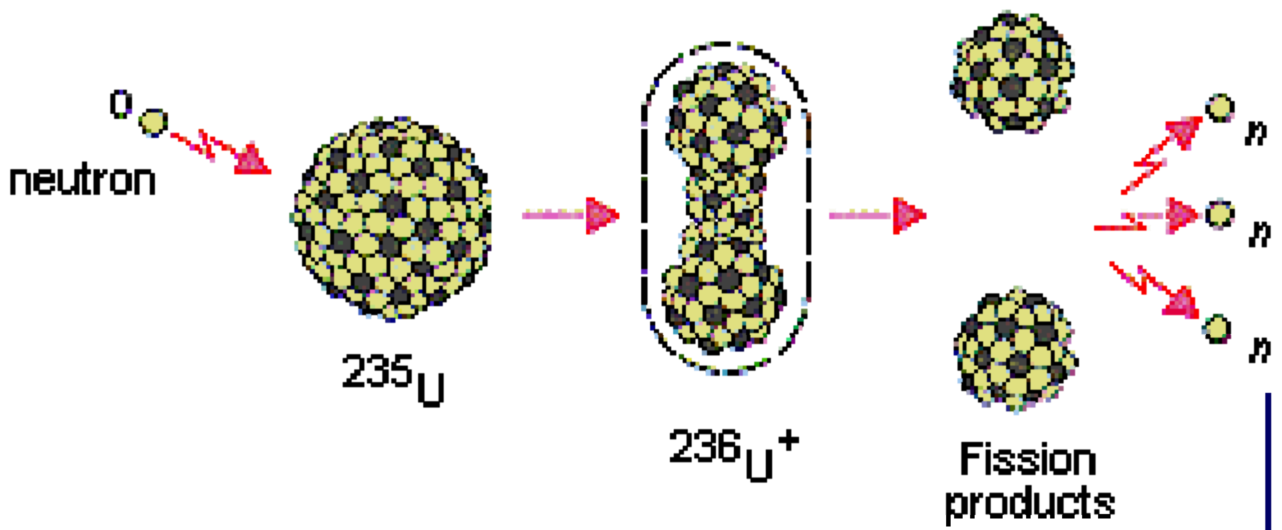
...e.g. the more muscles, the more Potassium 40..

Artificial Radioactivity

Reaction Mechanism:

- *Fusion*
- Fission
- High Energy Nuclear Reaction (Spallation)
- more hadronic nuclear reactions (p,n), (n,γ), ...
- Gamma induced nuclear reaction (γ,n)

Fission

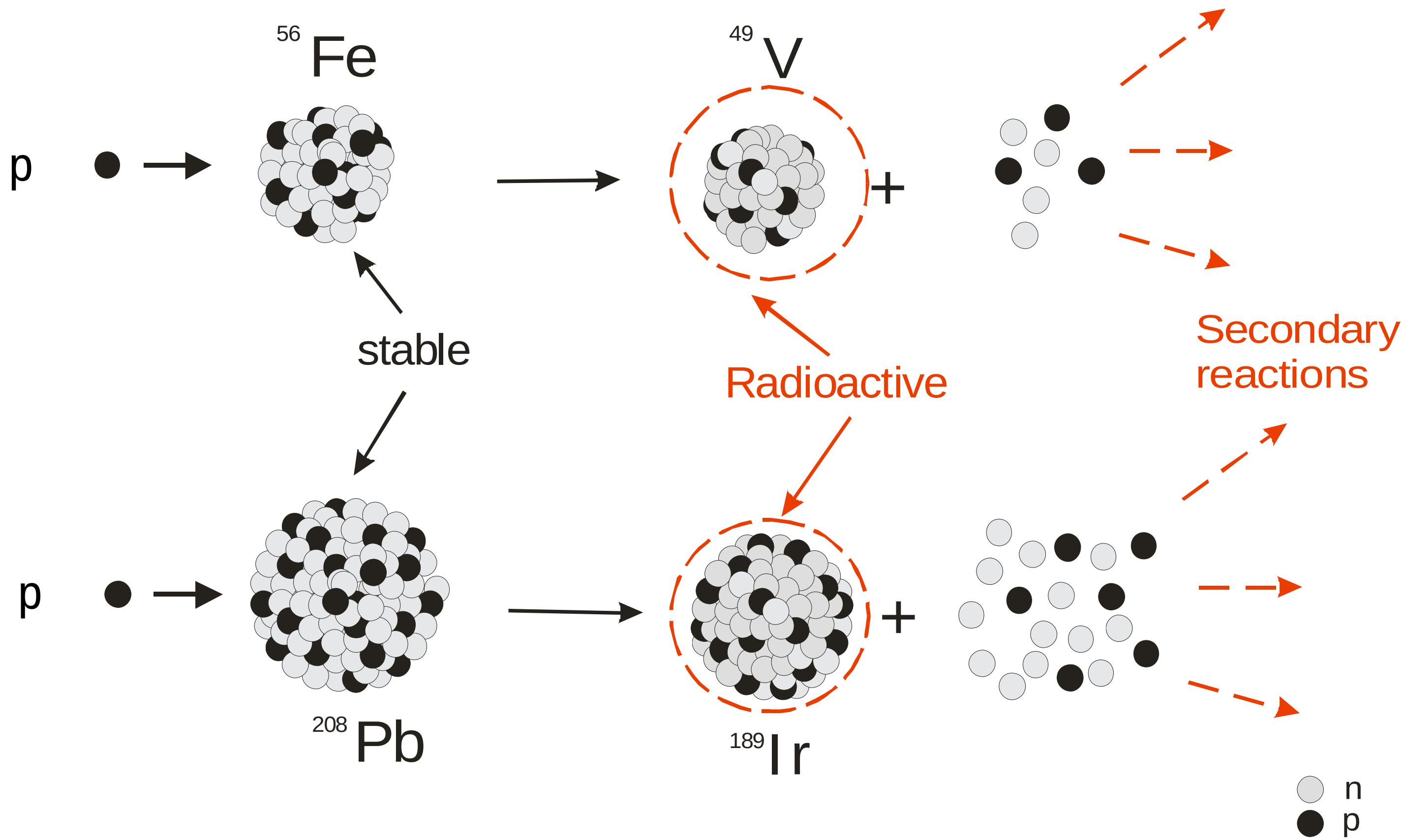


thermal
neutron capture

$^{59}Co + n \rightarrow {}^{60}Co$

$^{23}Na + n \rightarrow {}^{24}Na$

Spallation

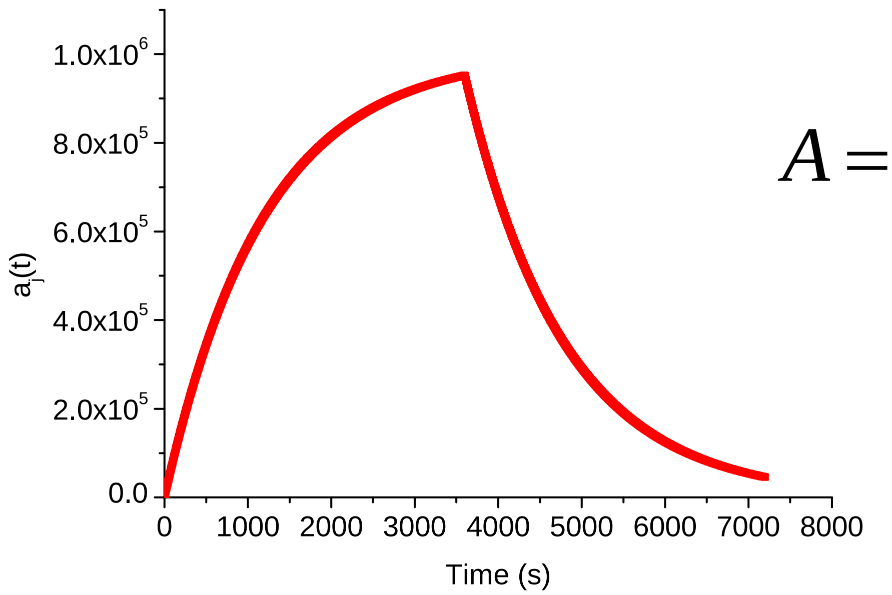


56 Fe
49 V
p
+
stable
Radioactive
Secondary reactions
p
+
208 Pb
189 Ir
n
p

Production and Decay of Radionuclides

Rule-of-thumb (probably very obvious):

the shorter the half-life, the faster the build-up, the faster the decay



$$A = A_s \left(1 - e^{-t_{irr}/\tau}\right) e^{-t_{dec}/\tau}$$

t_{irr} irradiation time
t_{dec} decay time
τ mean lifetime
$\ln(2) = \tau \times T_{1/2}$

It takes about 5 half-lives to reach saturation of activity

When is a material radioactive?

- **Activity**
  - *Specific activity* exceeds the CERN exemption limits as given in Table 2 (column 2) of EDMS doc 942170

  AND
  - *total activity* exceeds the CERN exemption limits as given in Table 2 (column 2) of EDMS doc 942170.

OR

- **Dose rate**
  - Ambient dose equivalent rate measured in 10 cm distance of the item exceeds 0.1 uSv/h after subtraction of the background.
    - Slightly radioactive < 10 uSv/h
    - Radioactive < 100 uSv/h
    - Highly radioactive > 100 uSv/h

OR

- **Surface contamination**
  - 1 Bq/cm^2 in case of unidentified beta- and gamma emitters and 0.1 Bq/cm^2 in case of unidentified alpha emitters. Once a radio-nuclide has been identified then the *CS*-values given in Table 4 of EDMS doc 942170 can be used.

When is a material radioactive?

CERN
CH1211 Genève 23
Suisse

Nº EDMS	REV.	VALIDITÉ
942170	3.0	

RÉFÉRENCE

Date: 02-12-2009

Operational Radiation Protection Rule

Exemption and Clearance of Material at CERN

DOCUMENT PRÉPARÉ PAR :	DOCUMENT VÉRIFIÉ PAR :	DOCUMENT APPROUVÉ PAR :
S. Roesler / DG-SCR C. Theis / DG-SCR	N. Conan / DG-SCR T. Otto / DG-SCR L. Ulrici / DG-SCR Heinz Vincke / DG-SCR M. Widorski / DG-SCR	D. Forkel-Wirth / DG-SCR

GROUPE D'APPROBATION

RÉFÉRENCE

Nº EDMS	REV.	VALIDITÉ
942170	3.0	

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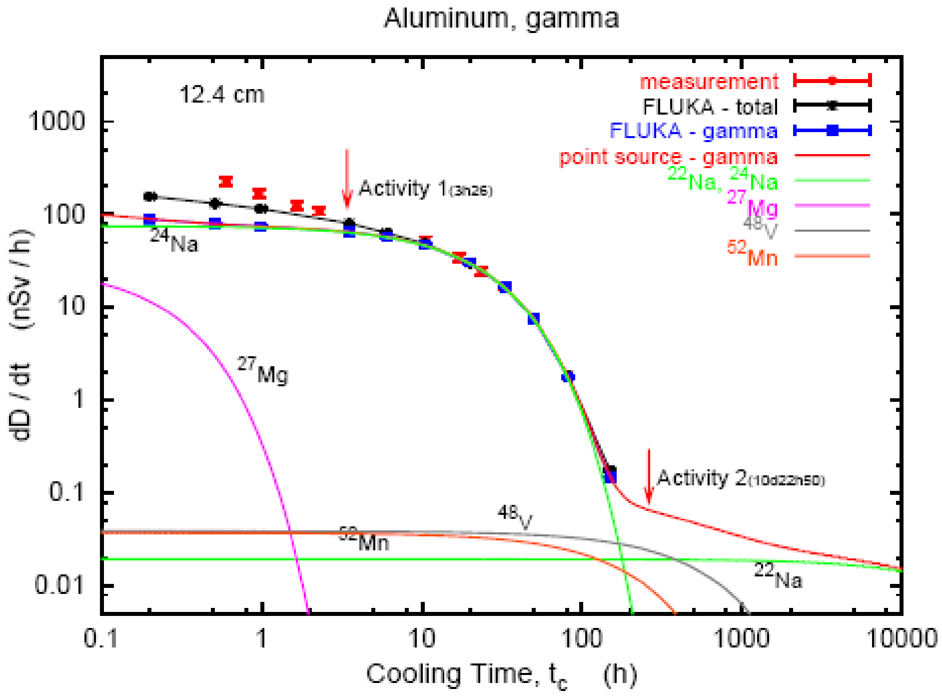
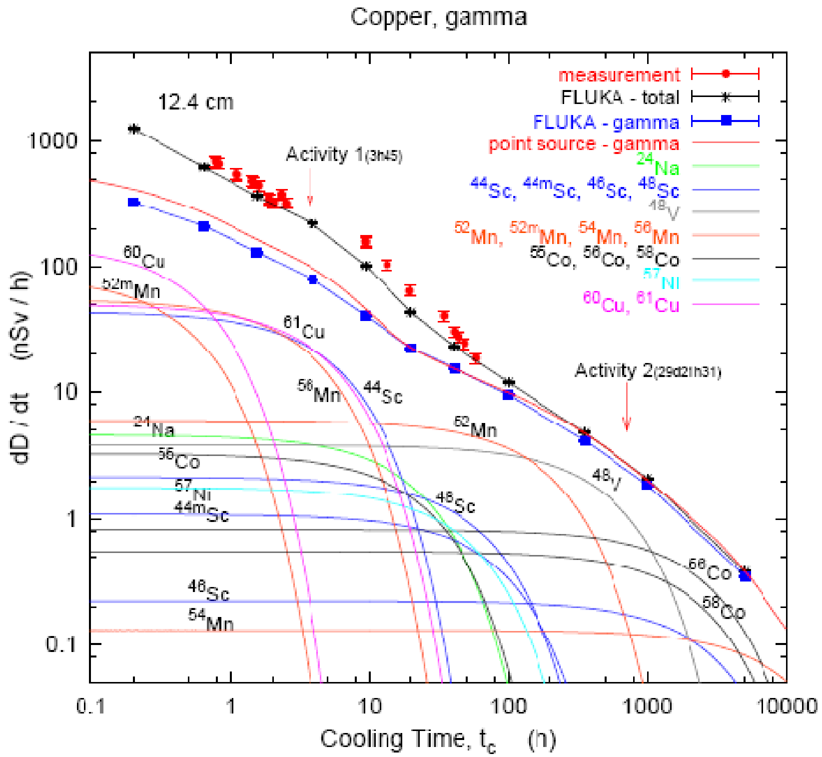
Nuclide	LE [Bq/kg] and LE_{abs} [Bq], Operation	LE [Bq/kg] and LE_{abs} [Bq], Design studies
V-47	2.00E+05	2.00E+05
V-48	5.00E+03	1.00E+03
V-49	6.00E+05	6.00E+05
Cr-48	5.00E+04	5.00E+04
Cr-49	2.00E+05	2.00E+05
Cr-51	3.00E+05	1.00E+05
Mn-51	1.00E+05	1.00E+03
Mn-52	6.00E+03	1.00E+03
mMn-52	1.00E+05	1.00E+03
Mn-53	3.00E+05	1.00E+05
Mn-54	1.00E+04	1.00E+02
Mn-56	4.00E+04	1.00E+03
Fe-52	7.00E+03	1.00E+03
Fe-55	3.00E+04	3.00E+04
Fe-59	6.00E+03	1.00E+03
Fe-60	9.00E+01	9.00E+01
Co-55	9.00E+03	1.00E+03
Co-56	4.00E+03	1.00E+02
Co-57	5.00E+04	1.00E+03
Co-58	1.00E+04	1.00E+03
mCo-58	4.00E+05	4.00E+05
Co-60	1.00E+03	1.00E+02
mCo-60	6.00E+06	1.00E+05
Co-61	1.00E+05	1.00E+04
mCo-62	2.00E+05	1.00E+03
Ni-56	1.00E+04	1.00E+04
Ni-57	1.00E+04	1.00E+04
Ni-59	2.00E+05	1.00E+05
Ni-63	7.00E+04	7.00E+04
Ni-65	6.00E+04	1.00E+03
Ni-66	3.00E+03	3.00E+03
Cu-60	1.00E+05	1.00E+05
Cu-61	8.00E+04	8.00E+04
Cu-62	1.00E+04	1.00E+04
Cu-64	8.00E+04	1.00E+04
Cu-66	3.00E+03	3.00E+03
Cu-67	3.00E+04	3.00E+04
Zn-62	1.00E+04	1.00E+03
Zn-63	1.00E+05	1.00E+04

Activation of Material at Hadron Accelerators

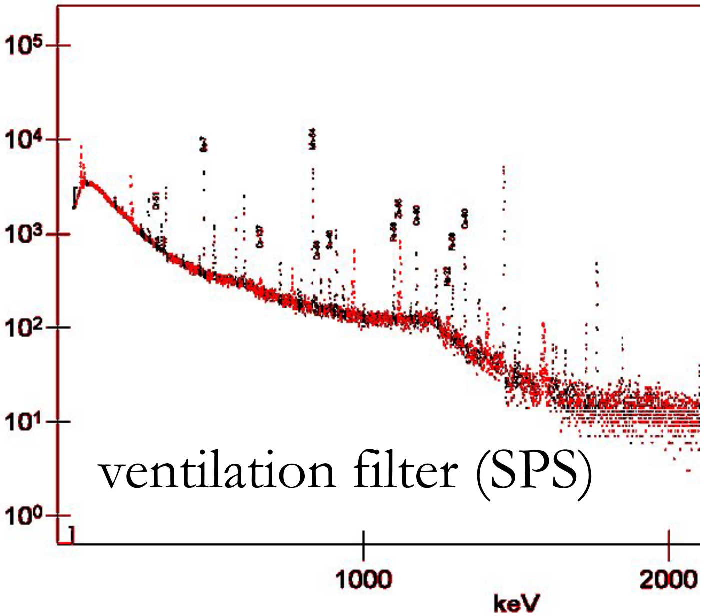
Beam losses result in the activation of material
(beam line components, tunnel structure, etc.)





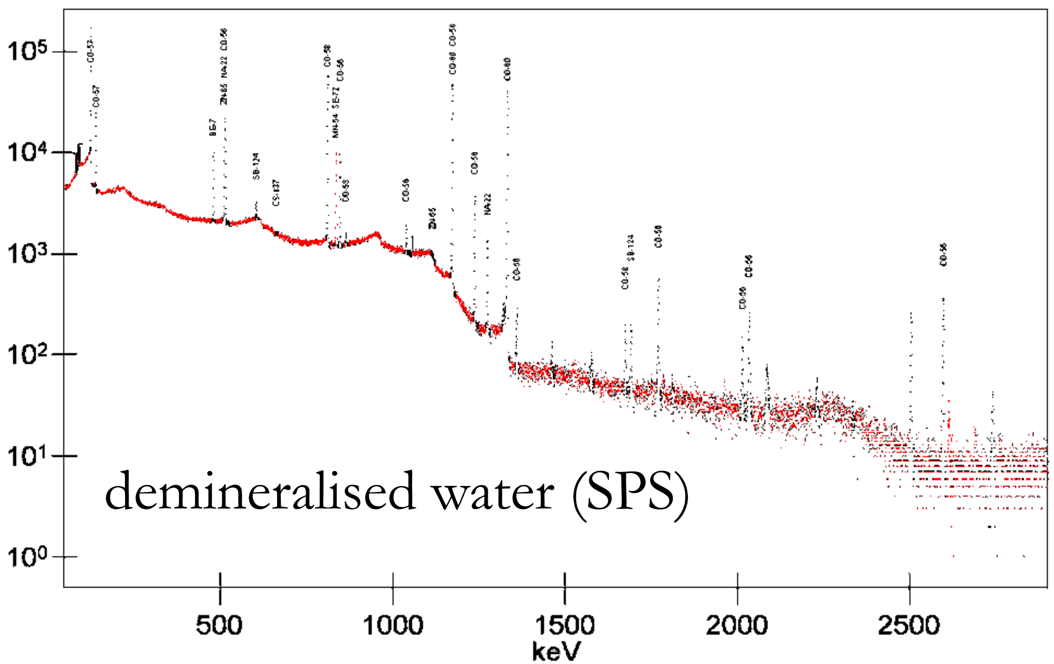
Activation

of air, gas, water, cooling liquids at hadron accelerators



Nuclide	Halflife
Be-7	53 D
Na-22	3 Y
Sc-46	84 D
Cr-51	28 D
Mn-54	312 D
Co-56	77 D
Fe-59	45 D
Co-60	5 Y
Zn-65	244 D

γ-emitter only



Nuclide	Halflife
BE-7	53 D
NA-22	3 Y
CO-56	77 D
CO-57	271 D
CO-58	71 D
CO-60	5 Y
ZN-65	244 D
SB-124	60 D

γ-emitter only

Radiological Quantities and Units

Absorbed Dose D: energy absorbed per mass

Unit: 1 Gy = 1 J/kg

[1 Gy = 100 rad]

$$D = \frac{1}{m}\int E dV$$

Equivalent Dose H: absorbed dose of organs weighted by the radiation weighting factor w_R of radiation R:

Unit: 1 Sv (= w_R x Gy)

[1 Sv = 100 rem]

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

Effective dose E: Sum of all equivalent doses weighted with the weighting factor w_T for tissue T

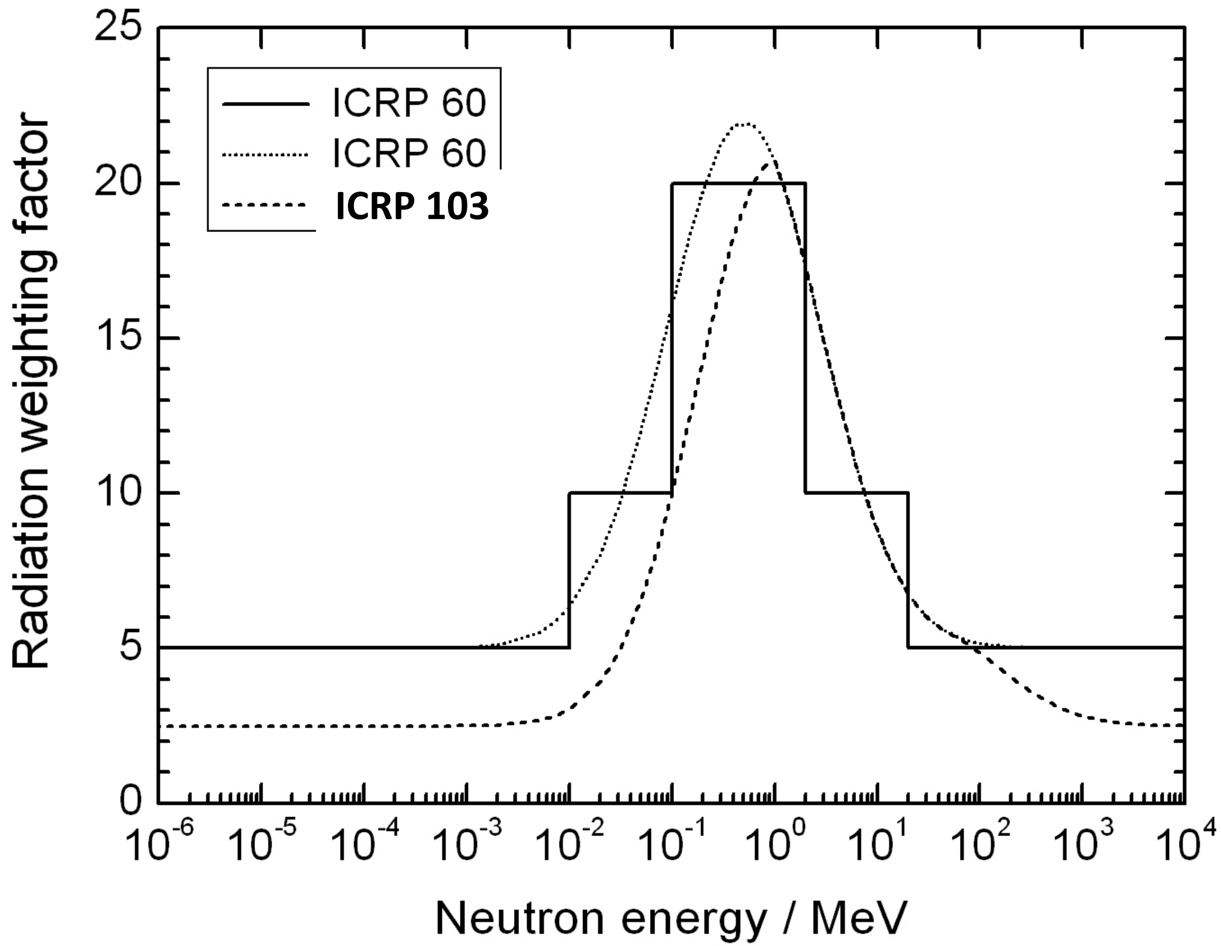
Unit: 1Sv

$$E = \sum_T w_T H_T$$

Radiation Weighting Factors

Type and energy of radiation R	Radiation weighting factor, w_R
Photons, all energies	1
Electrons and muons, all energies	1
Neutrons:	
<10 keV	5
10 to 100 keV	10
> 0.1 to 2 MeV	20
> 2 to 20 MeV	10
> 20 MeV	5
Protons, other than recoil protons, E > 2 MeV ICRP 103 (protons and charged pions)	5 (2)
Alpha particles, fission fragments, heavy nuclei	20

Neutron Radiation Weighting Factors (ICRP 103)



Values for neutrons replaced by a continuous function in ICRP 103 (2007)

Biological Effects

Stochastic effects:

no dose threshold (linear function of dose)

increase of probability by 5% per Sv for:

- genetic defects
- cancer

result does not depend on the amount of absorbed dose but the probability of having the effects is proportional to the dose absorbed.

delayed health detriments

Deterministic effects:

dose received in short time interval
dose threshold: > 500 mSv

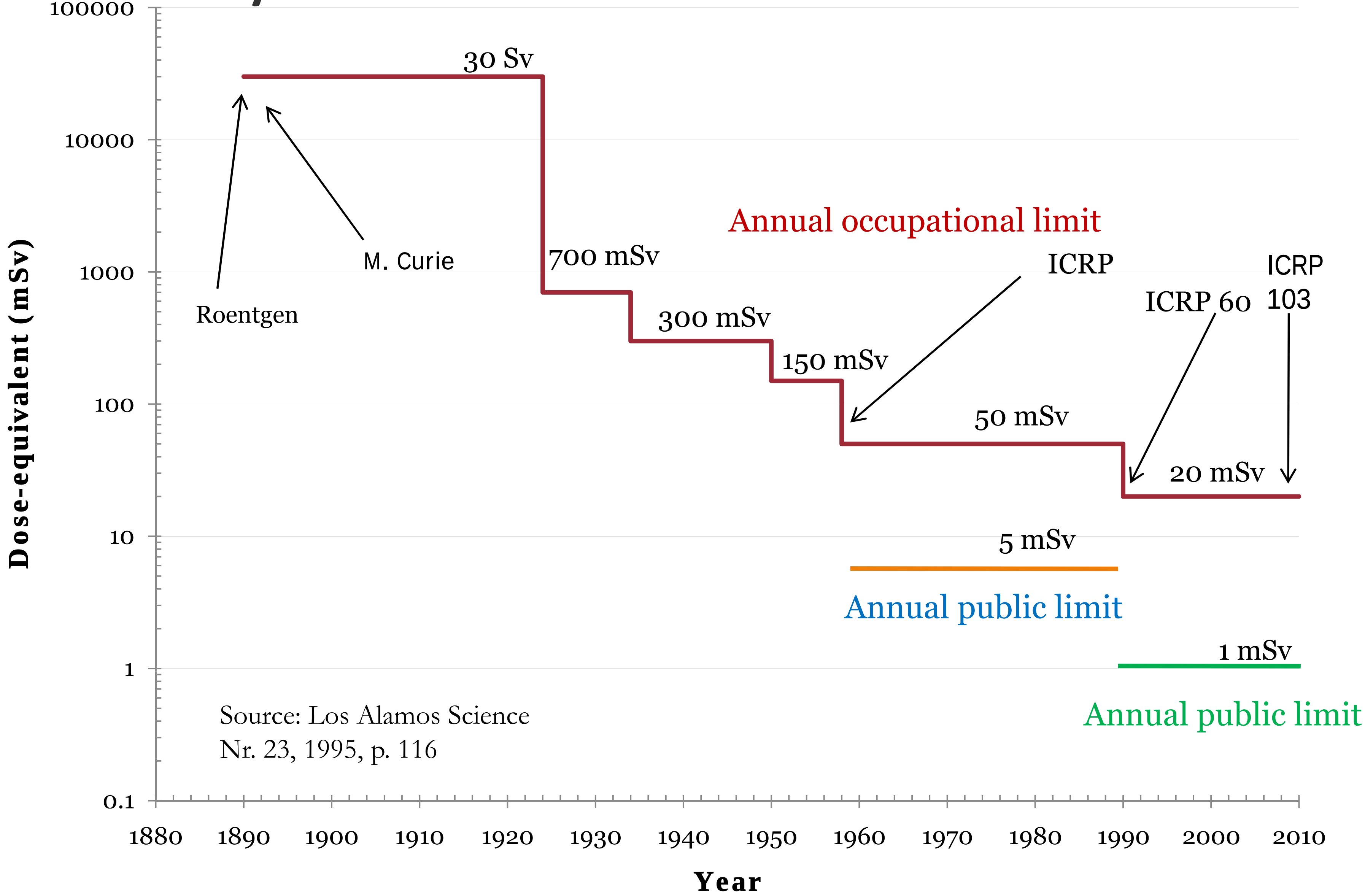
immediate consequences:

- vomiting
- immun deficiency
- erythema and necrose

health detriments are function of the dose

lethal dose: 5 – 7 Sv

History of Radiation Protection



General Principles of Radiation Protection Legislation

1) Justification

any exposure of persons to ionizing radiation has to be justified

2) Limitation

the personal doses have to be kept below the legal limits

3) Optimization

the personal doses and collective doses have to be kept as low as reasonable achievable (ALARA)

Dose Limits

	Dose limits for 12 months consecutive (mSv)		
	Non-occupationally exposed persons	Occupationally exposed persons	
		B	A
EURATOM	< 1	< 6	< 20
Germany/France	< 1	< 6	< 20
CERN	< 1	< 6	< 20
Switzerland	< 1	< 20	

Radiation Area Classification – One Mean to Limit Doses

CERN

Area	Dose limit [year]	Ambient dose equivalent rate		Sign (RADIATION ZONE SURVEILLÉE / RADIATION ZONE CONTRÔLÉE CONTROLLED AREA)
		Work place	Low occupancy	
Non-designated	1 mSv	0.5 µSv/h	2.5 µSv/h	
Supervised	6 mSv	3 µSv/h	15 µSv/h	Dosimeter obligatory Dosimètre obligatoire
Simple	20 mSv	10 µSv/h	50 µSv/h	Dosimeter obligatory Dosimètre obligatoire
Limited Stay	20 mSv		2 mSv/h	LIMITED STAY SÉJOUR LIMITÉ Dosimeters obligatory Dosimètres obligatoires
High Radiation	20 mSv		100 mSv/h	HIGH RADIATION HAUTE RADIATION Dosimeters obligatory Dosimètres obligatoires
Prohibited	20 mSv		> 100 mSv/h	PROHIBITED AREA ZONE INTERDITE No Entry Défense d'entrer

Radiation Area (Supervised to Prohibited)

Controlled Area (Simple to Prohibited)

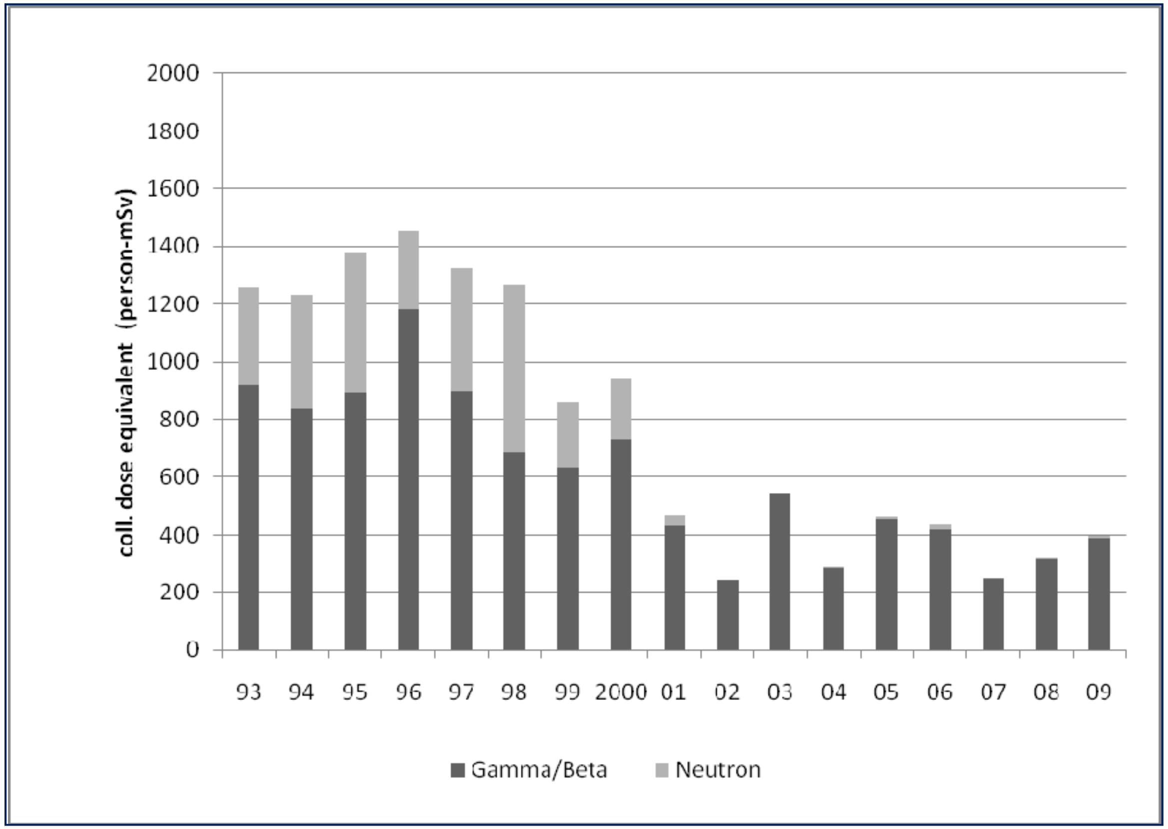
Courtesy N. Conan, M. Widorski

Safety Instruction S3-GSI1, EDMS 810149

Optimization

- Any justified job is considered as optimized when different appropriate solutions have been evaluated and judged against each other from the radiation protection viewpoint,
- The decisional process leading to the chosen solution can be reconstructed at any time, and the risk of failure and the elimination of radioactive sources have been taken into account.
- Optimisation can be considered as respected if the activity never gives rise to an annual dose of more than 100 μSv for persons professionally exposed or 10 μSv for members of the public

Occupational Exposure of CERN Personnel



Evolution of collective dose equivalent for personnel monitored in person-mSv per year

The decrease of collective neutron dose equivalent is due to the subtraction of natural background (1999) and to the introduction of a technically more advanced dosimeter (2001).

Distribution of Personal Annual Doses

Dose interval (mSv)	Persons Concerned (2005)	Persons Concerned (2006)	Persons Concerned (2007)	Persons Concerned (2008)	Persons Concerned (2009)
0.0	3074	4192	5131	5143	5042
0.1-0.9	1522	1738	898	1020	1219
1.0-1.9	53	37	33	40	39
2.0-2.9	9	17	2	3	13
3.0-3.9	3	4	1	1	2
4.0-4.9	4	2	1	1	-
5.0-5.9	1	-	-	-	-
> 6.0	-	-	-	-	-

Distribution of personal annual dose equivalent from 2004 on in intervals of increasing personal dose. The majority of monitored persons did not receive any personal dose. In 2009 only 54 persons exceeded an annual dose of 1 mSv.

CERN Reference Levels

Year	Number of persons with effective doses above 6 mSv/year	Activity
2000	13	Cable changes, beam instrumentation, transport, radiation protection
2001	2	Transport, maintenance of beam instrumentation
2002	2	Transport
2003	5	Transport, radiation protection, Gamma radiography
2004	0	
2005	0	
2006	0	
2007	0	
2008	0	
2009	0	

Occupationally exposed workers:
Annual individual, effective dose should stay below 6 mSv

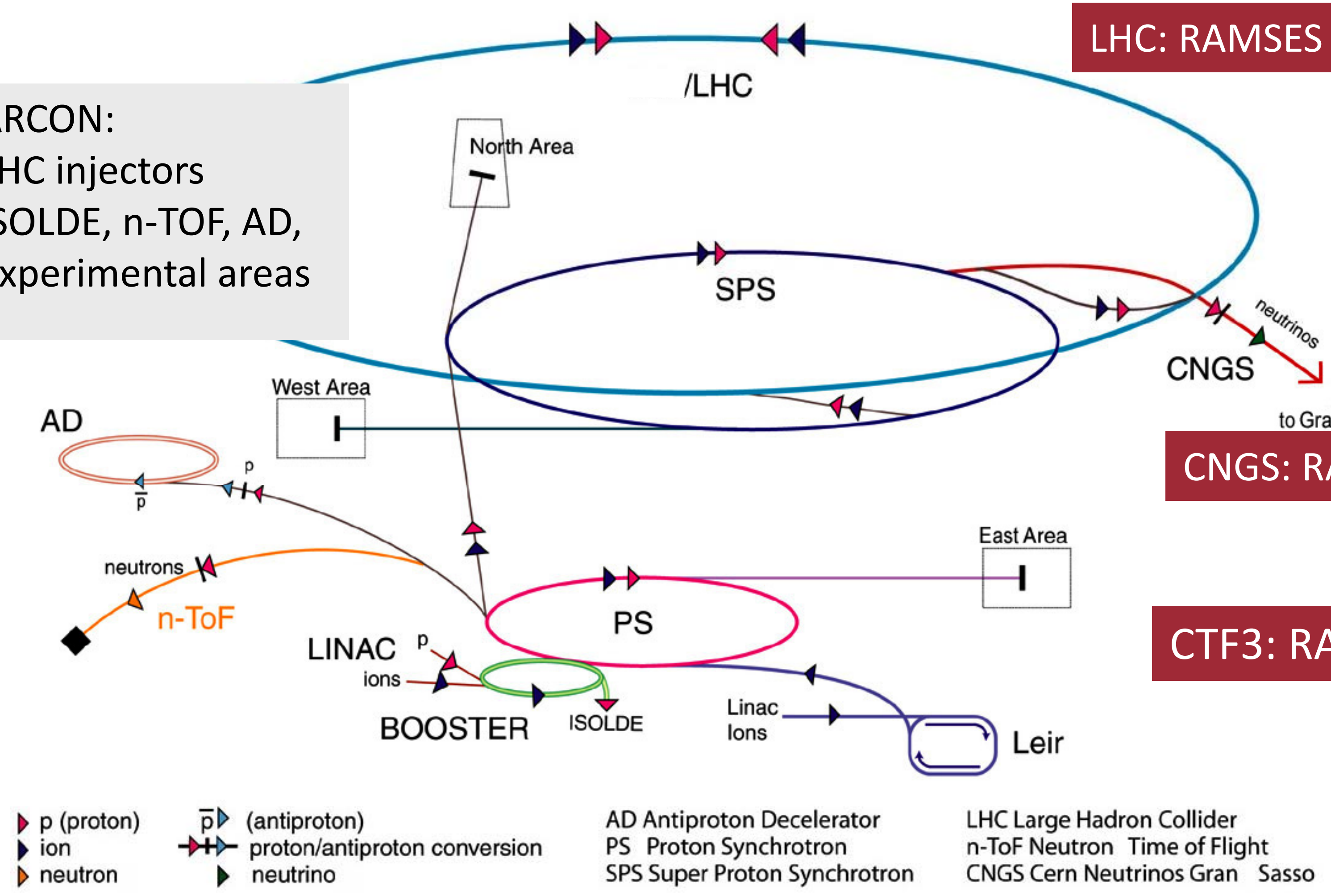
Radiation Monitoring - ARCON/RAMSES

ARCON:
LHC injectors
ISOLDE, n-TOF, AD,
Experimental areas

LHC: RAMSES

CNGS: RAMSES

CTF3: RAMSES



Monitors for Protection of Environment

ARCON and RAMSES use the same/similar type of monitors

Stray radiation Monitoring

EPIC

ERC

Water Monitoring station

RWM - RWS

Ventilation Monitoring

VGM - VAS

Wind onitoring

USA

Operational Radiation Protection Monitors

ARCON and RAMSES use the same/similar type of monitors

REM counter

Gas filled, high pressure ionization chamber

Beam-on: to protect workers in areas adjacent to accelerator tunnels and experiments against prompt radiation (mainly neutrons, E < some GeV)
Alarm function

Air filled ionisation chamber

Beam-off: to protect workers during maintenance and repair against radiation fields caused by decay of radionuclides (mainly gammas, E < 2.7 MeV)
No alarm function

Operational Radiation Protection Monitors

Special monitors

Hand&Foot monitor

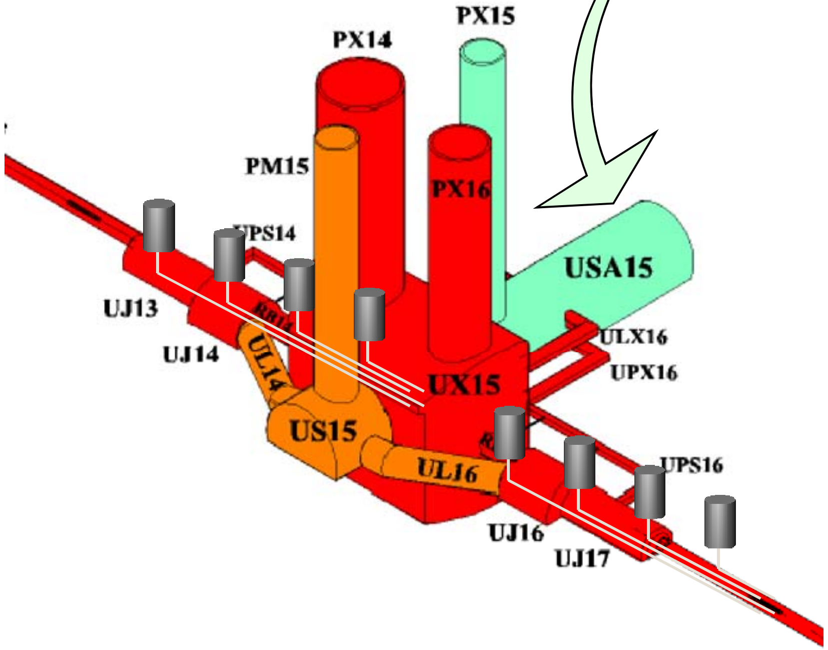
Site Gate Monitor

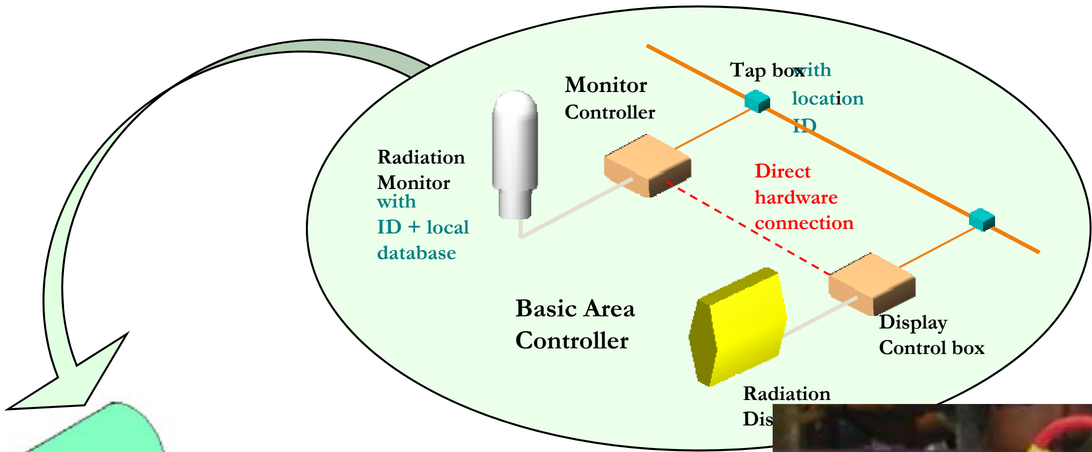
Monitoring station

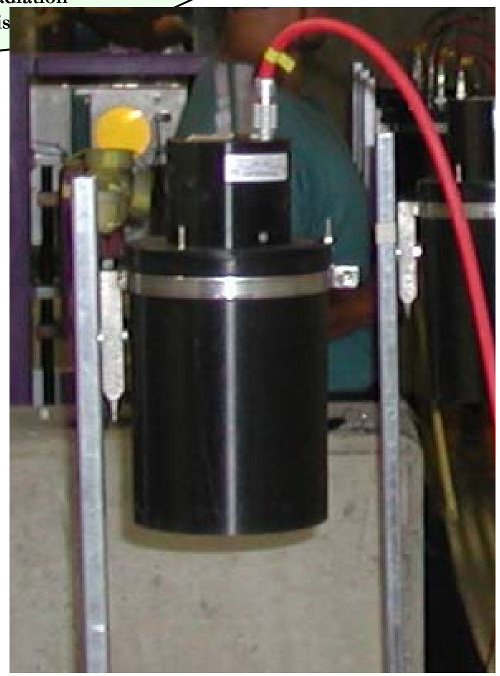
RAMSES: reading of radiation levels directly available ≠ ARCON

Radiation Alarm Unit (RAMSES)

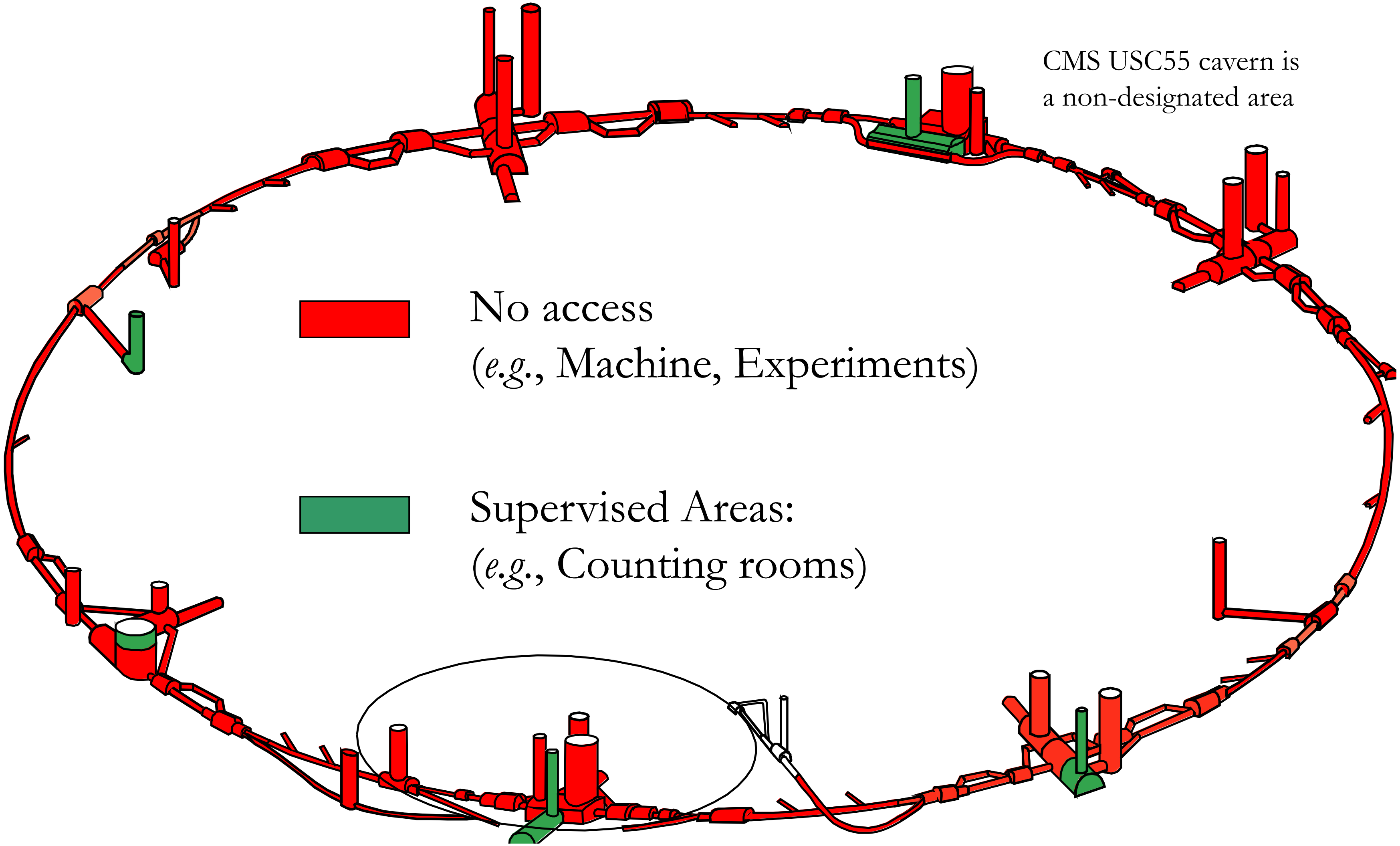
LHC Area Monitoring

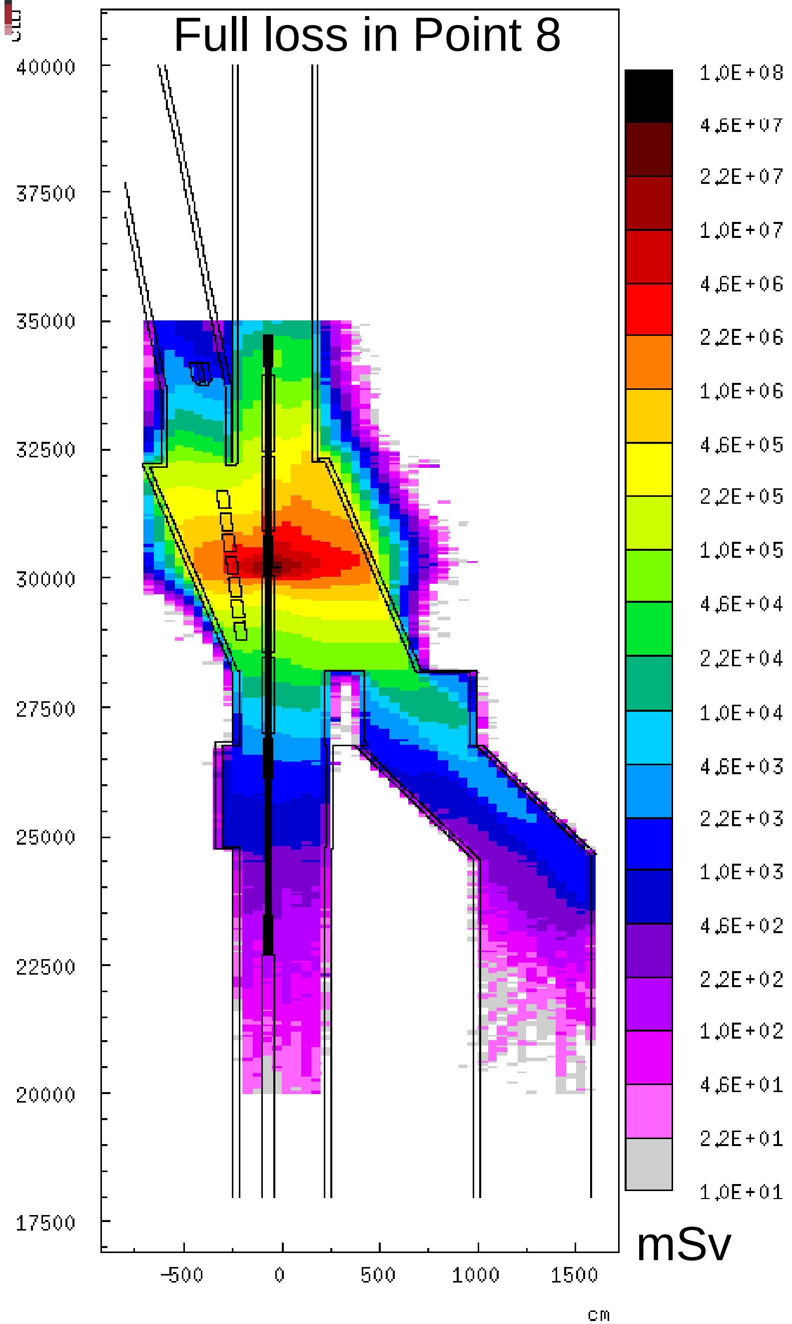






LHC Area Classification – Beam On





Distance to beam line (without shielding)	Dose for full beam loss (Gy)	Dose rate at quench limit (Sv/h)	Dose rate caused by beam gas interactions (mSv/h)	
			ultimate	nominal
1 m	5500	10	20	14
2 m	2500	5	10	7
3 m	1200	3.3	7	5
5 m	500	2	4	3

Remark: all dose and dose rates have to be doubled inside and increased by a factor of 20 % to 30 % outside due to photonic contribution

Quench limit: 1E7 protons/(m s)

Beam gas interactions (ultimate): ~1E16/year (200 days) ➔ 21400/(m s)

Attenuation of concrete:

100 cm concrete ➔ factor ~ 10

200 cm concrete ➔ factor ~ 100

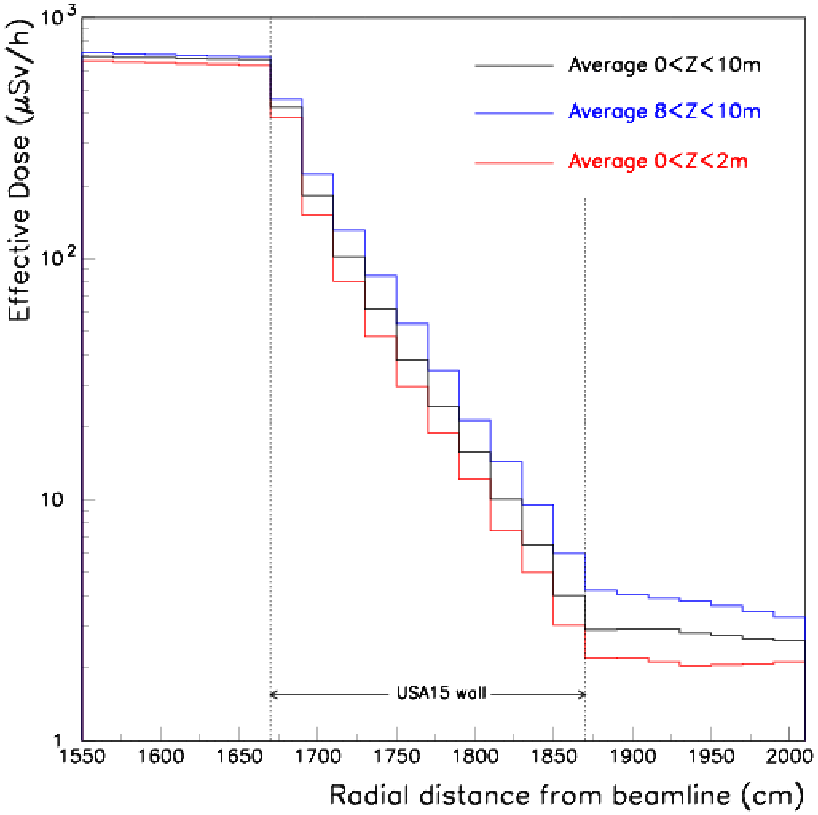
300 cm concrete ➔ factor ~ 1000

Sv/Gy: approximated with 5

Design of ATLAS shielding

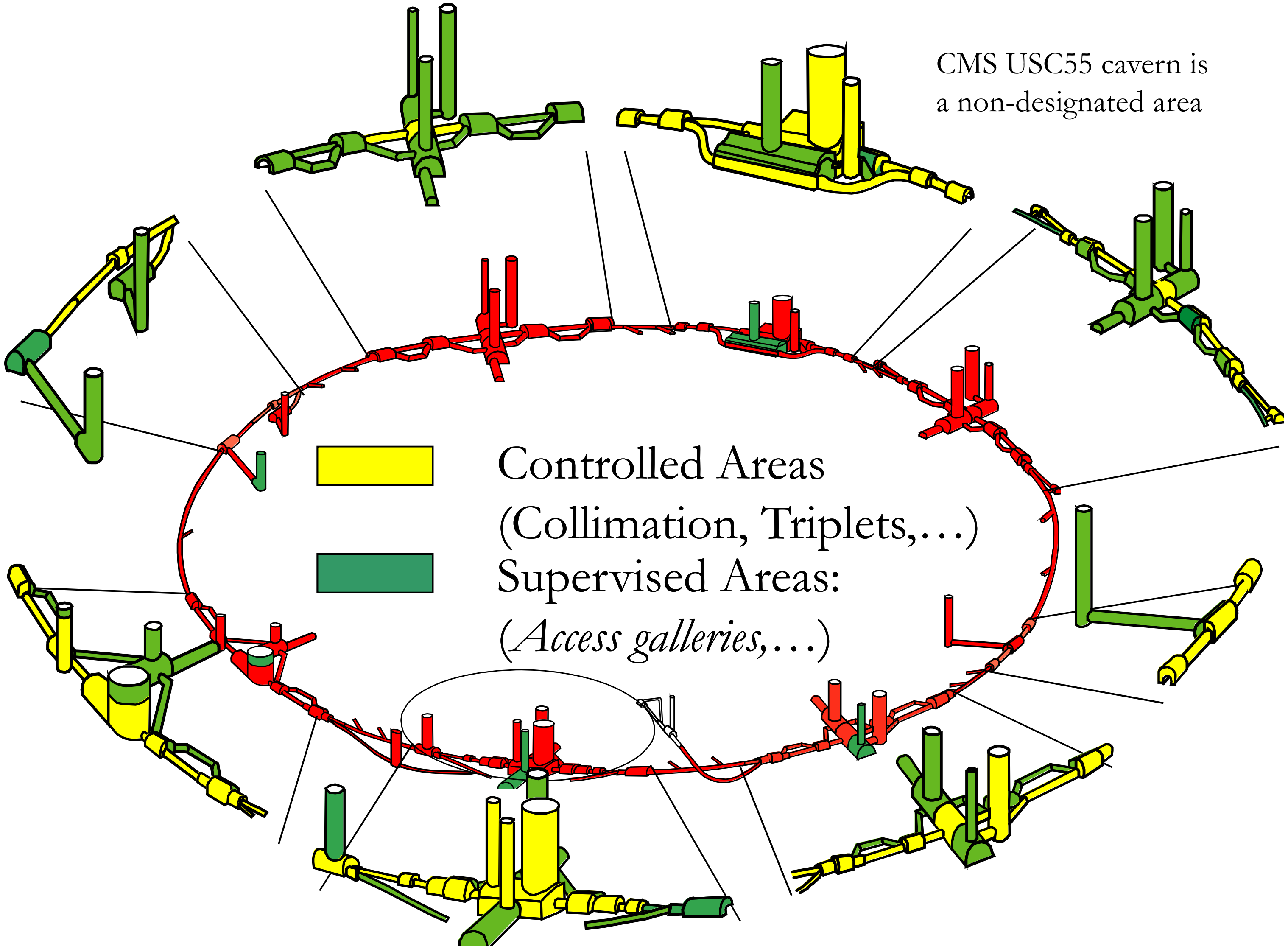
Effect of trigger holes is small (~15%). When these holes are filled their impact will be even smaller.

Dose rate varies in USA15 along the wall. Worst case are *~4 uSv/h*, and *~2uSv/h* in the central region where the trigger cable ducts are located.



Courtesy: Ian Dawson

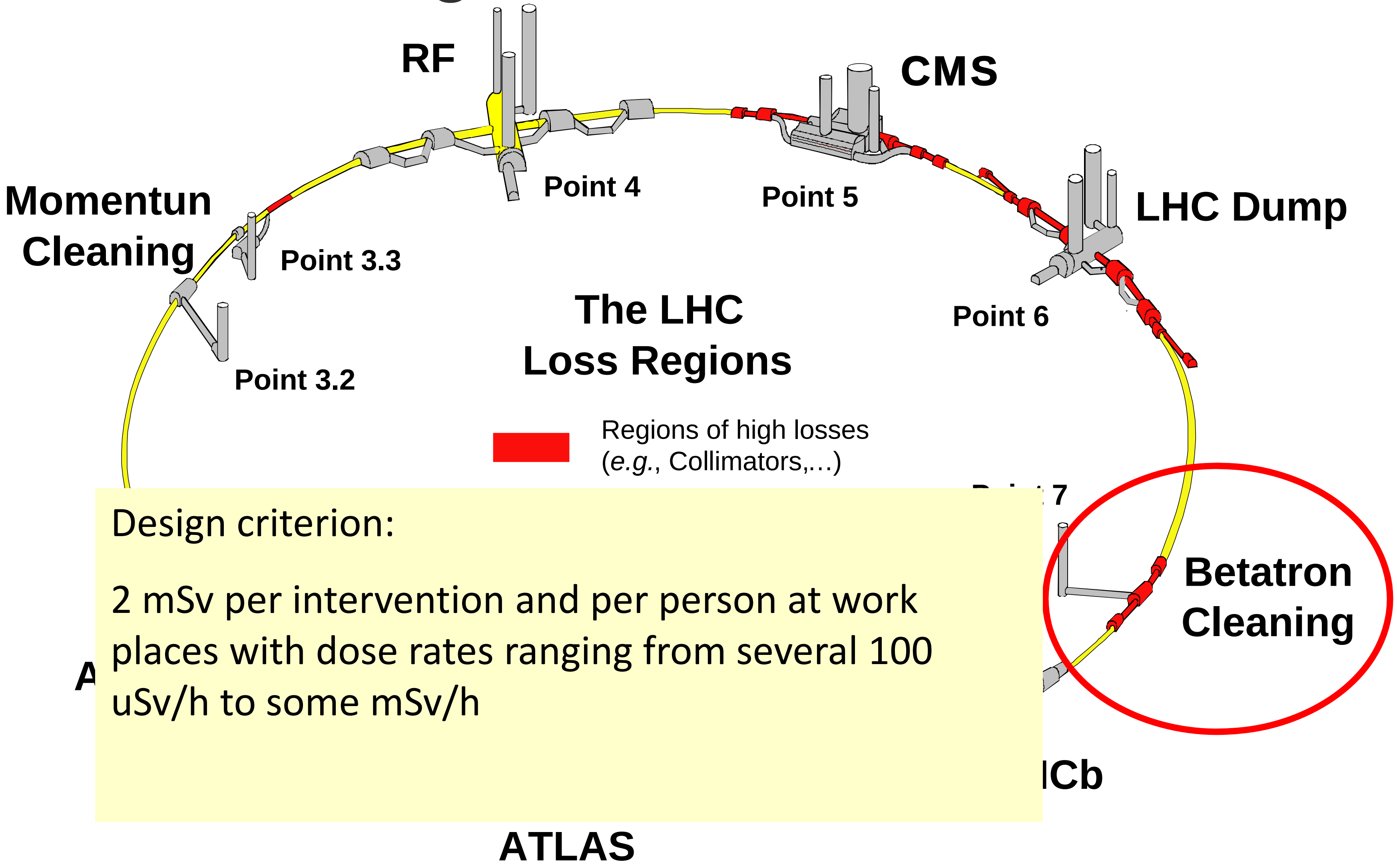
LHC Area Classification – Beam Off



Future Critical Regions of LHC

- Momentum and betatron cleaning regions at Points 3 and 7
- Beam dump caverns
- TCDQ/TCDS diluter system at Point 6
- TAS collimators in the ATLAS and CMS interfaces
- TAN neutral particle absorbers at Points 1 and 5
- Low-β regions at Points 1 and 5
- Dispersion suppressor regions at Points 1 and 5

Critical Regions

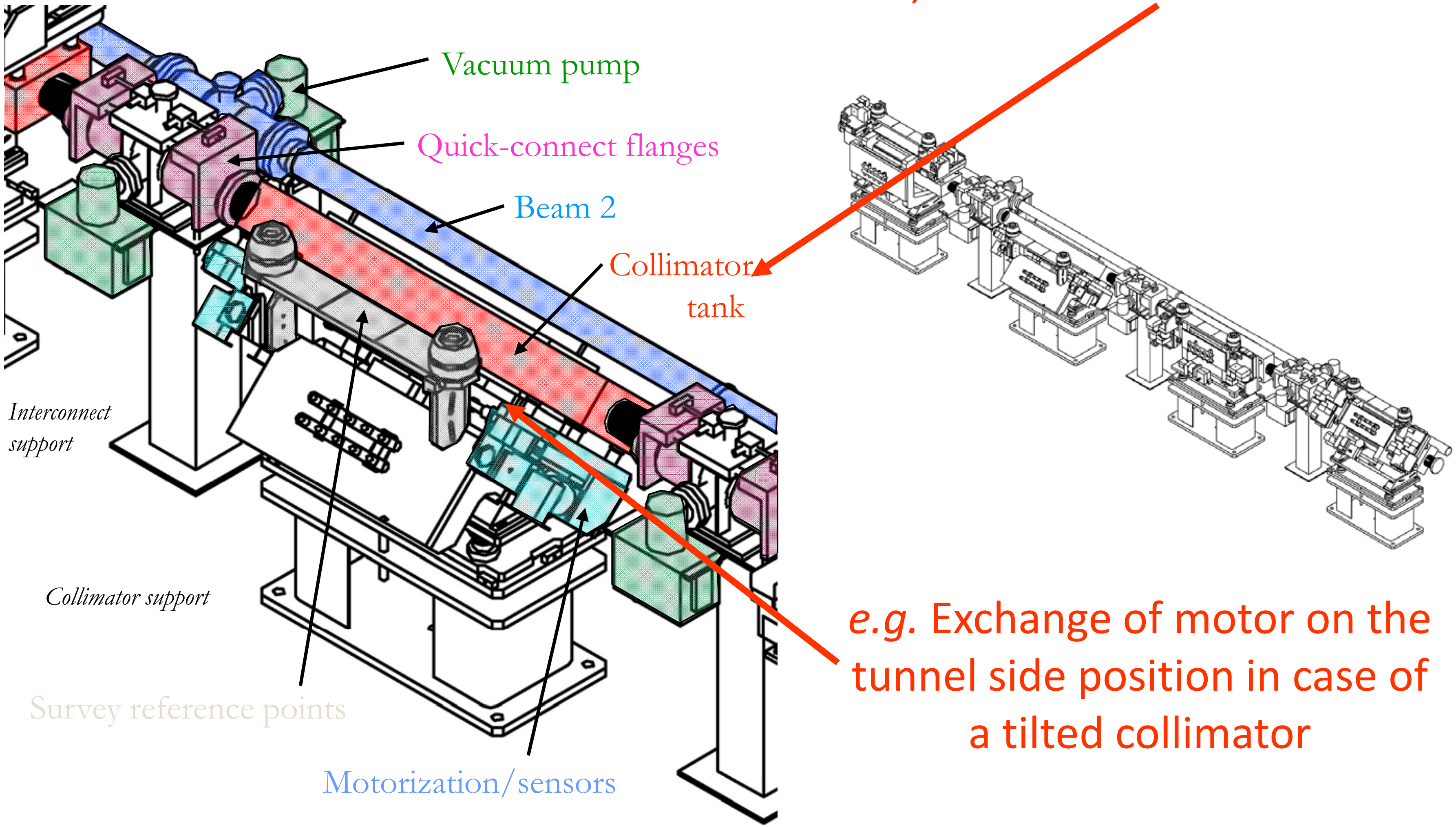


Design criterion:

2 mSv per intervention and per person at work places with dose rates ranging from several 100 uSv/h to some mSv/h

How does it look ?

Narrow, thus difficult access

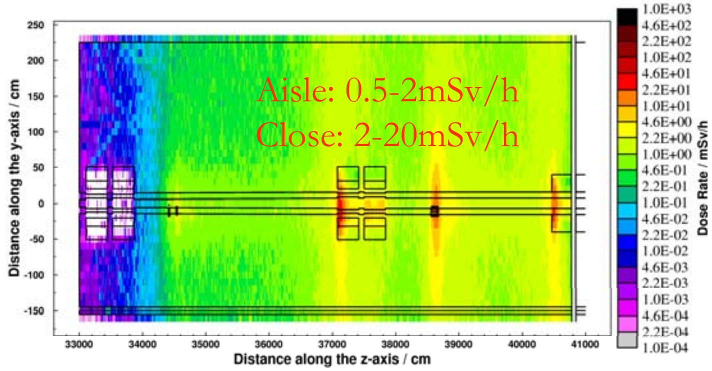


e.g. Exchange of motor on the tunnel side position in case of a tilted collimator

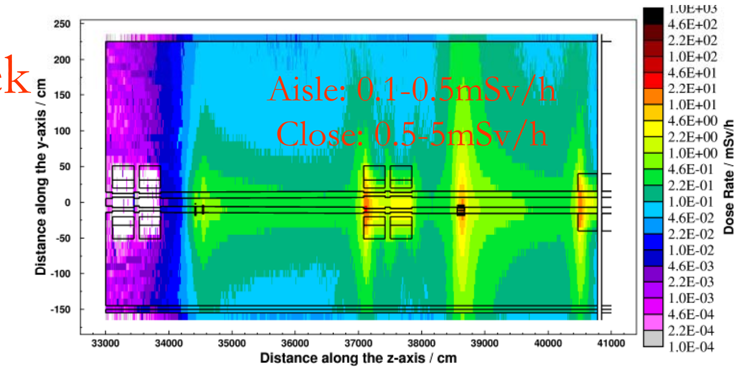
Detailed MC Calculations

- Remanent Dose Rates ranging from 0.1-20 mSv/h (cooling time of 8 hours to 4 months)
- Regular interventions
- Possible additional interventions on nearby elements (e.g., vacuum pumps, magnet modules, beam instrumentation
- Possible failure of elements

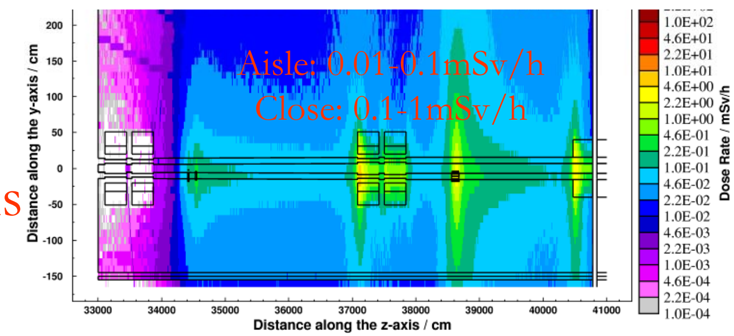
8 hours



1 week



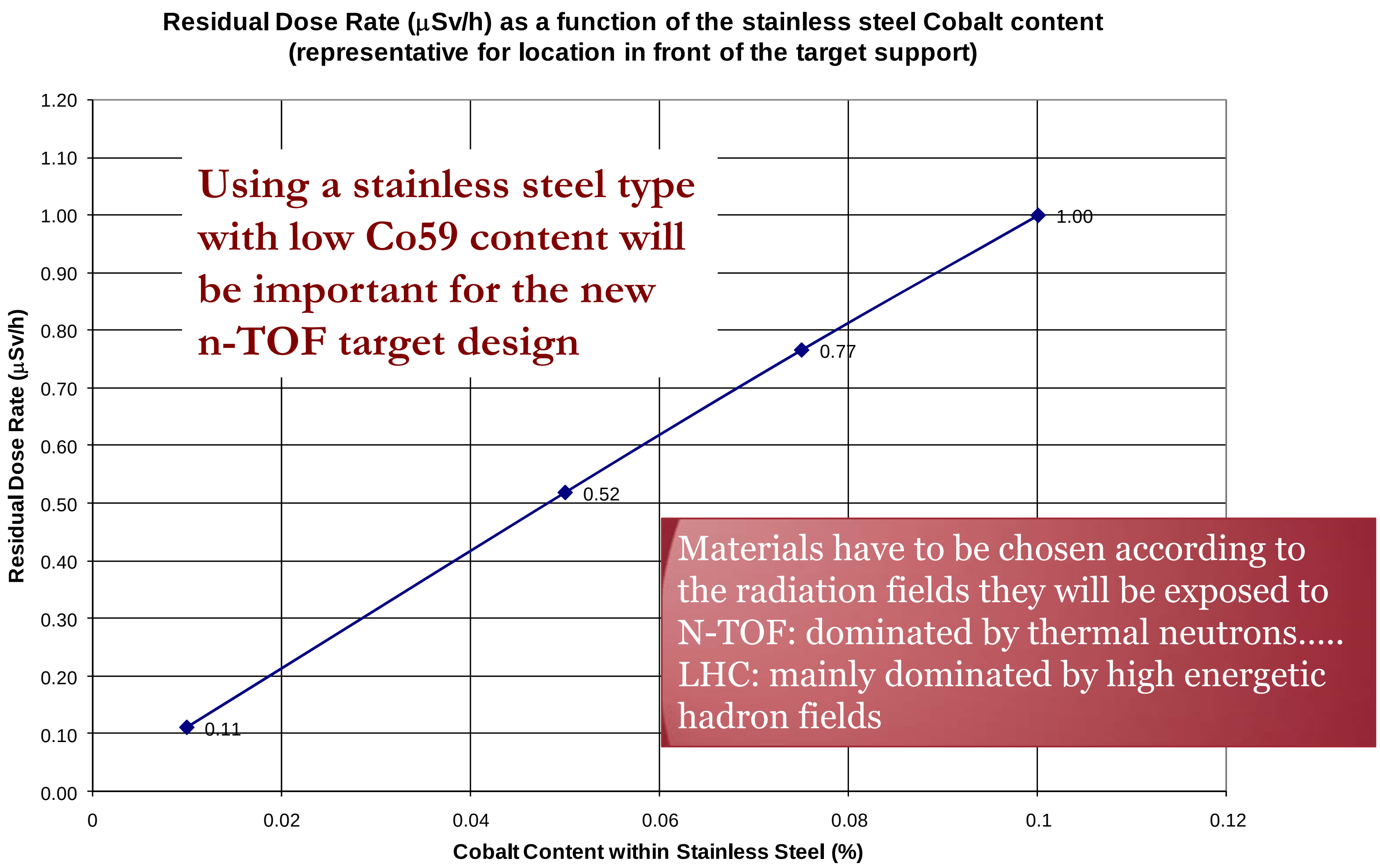
4 months



ALARA: Collimator Exchange LHC Point 7

Actions	Collective Dose / mSv					
	1h	8h	1d	1w	1m	4m
without permanent bakeout						
CF with bolts	54.5	38.7	26.5	12.3	7.2	3.1
CF with chain clamps	51.4	36.5	24.9	11.5	6.8	2.9
CF with bolts + 2nd beam line	99.4	70.7	48.0	21.8	12.9	5.6
CF with chain clamps+ 2nd beam line	95.3	67.8	45.9	20.7	12.3	5.3
with permanent bakeout						
CF with bolts	28.0	19.5	13.9	6.7	3.9	1.7
CF with chain clamps	24.9	17.3	12.3	5.9	3.4	1.5
CF with bolts+ 2nd beam line	46.3	32.2	22.8	10.7	6.2	2.7
CF with chain clamps+ 2nd beam line	42.2	29.3	20.7	9.6	5.5	2.4

Dependency on Cobalt Content



Courtesy M. Brugger, EN-STI

Implementation of ALARA at CERN

Already since December 2006:

- systematic, formalized approach
- Presently applied to the PS, ISOLDE, SPS and CNGS and LHC – to be extended to all work in radiation areas
- "close collaboration" between RP and the maintenance team and the RSO

All work in radiation areas has to be optimised

- Supervised Radiation Area: general optimisation by shielding, optimised installation of workplaces…
- Controlled Radiation Areas: All work must be planned and optimised including an estimate of the collective dose and of the individual effective doses to the workers participating in the completion of the task (Dossier D'Intervention en Milieu Radioactif - DIMR).

most of the ALARA elements were already used all over CERN in the past.

ALARA at CERN – 3 levels

CRITÈRE DE DÉBIT DE DOSE

Débit d'équivalent de dose prévisionnel ($\dot{H}$) dans la zone d'intervention :

niveau I	niveau II	niveau III
< **50 µSv·h^{-1}**	**50 µSv·h^{-1}** – **2 mSv·h^{-1}**	> **2 mSv·h^{-1}**

CRITÈRE DE DOSE INDIVIDUELLE

Équivalent de dose prévisionnel individuel (H_i) pour l'intervention, ou pour l'ensemble des interventions de même nature lorsque celles-ci sont répétées plusieurs fois sur une année :

niveau I	niveau II	niveau III
< **100 µSv**	**100 µSv** – **1 mSv**	> **1 mSv**

CRITÈRE DE DOSE COLLECTIVE

Équivalent de dose prévisionnel collective (H_C) pour l'intervention, ou pour l'ensemble des interventions de même nature lorsque celles-ci sont répétées plusieurs fois sur une année :

niveau I	niveau II	niveau III
< **500 µSv**	**500 µSv** – **10 mSv**	> **10 mSv**

CRITÈRE DE CONTAMINATION ATMOSPHÉRIQUE

Activité aérienne spécifique CA :

niveau I	niveau II	niveau III
< **5 CA**	**5 CA** – **200 CA**	> **200 CA**

CRITÈRE DE CONTAMINATION SURFACIQUE

Activité surfacique spécifique CA :

niveau I	niveau II	niveau III
< **10 CS**	**10 CS** – **100 CS**	> **100 CS**

For details see EDMS No: 810176

ALARA procedures – 3 levels:

- If the rad. risk is **low**
  <> very light procedure
- If it is **medium**
  <> an optimization effort is required
- If it is **high**
  <> an optimization effort is required, the procedure will be submitted to the ALARA committee

CERN aims to optimize

- work coordination
- work procedures
- handling tools
- design
- material

to reduce dose to personnel

ALARA

Starts already during at the design phase:

- Choose the right material
- Design the components for optimised maintenance and repair (imagine yourself maintaining a radioactive component)
- Design the whole facility for optimised maintenance and repair (optimised lay-out, space, cranes, easy access to equipment, etc.)
- Consider remote handling as an option

Examples:

- Use of plug-in systems, e.g. for collimators allowing short installation and replacement times.

ALARA

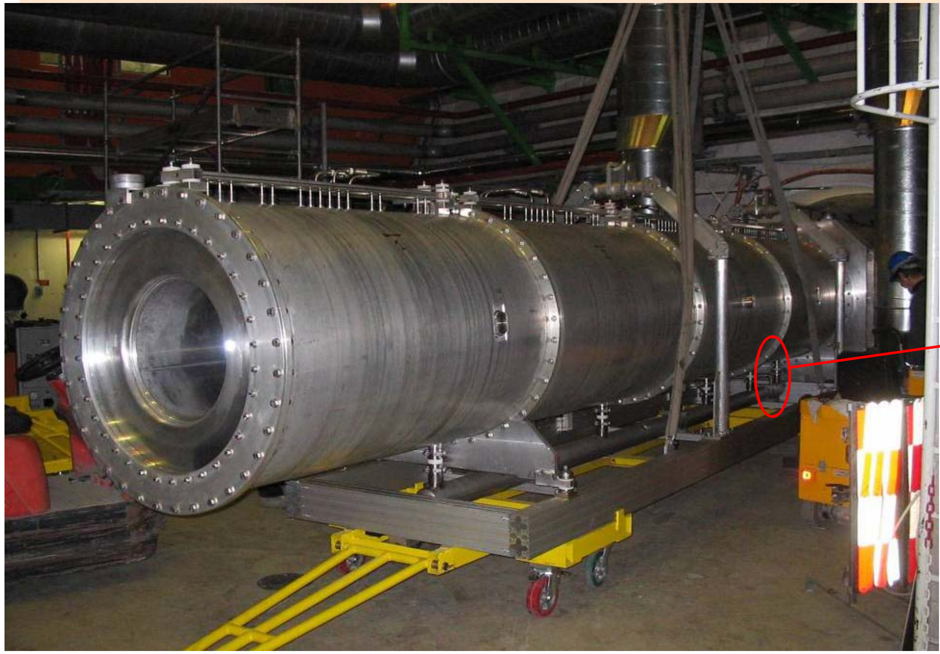
Starts already during at the design phase:

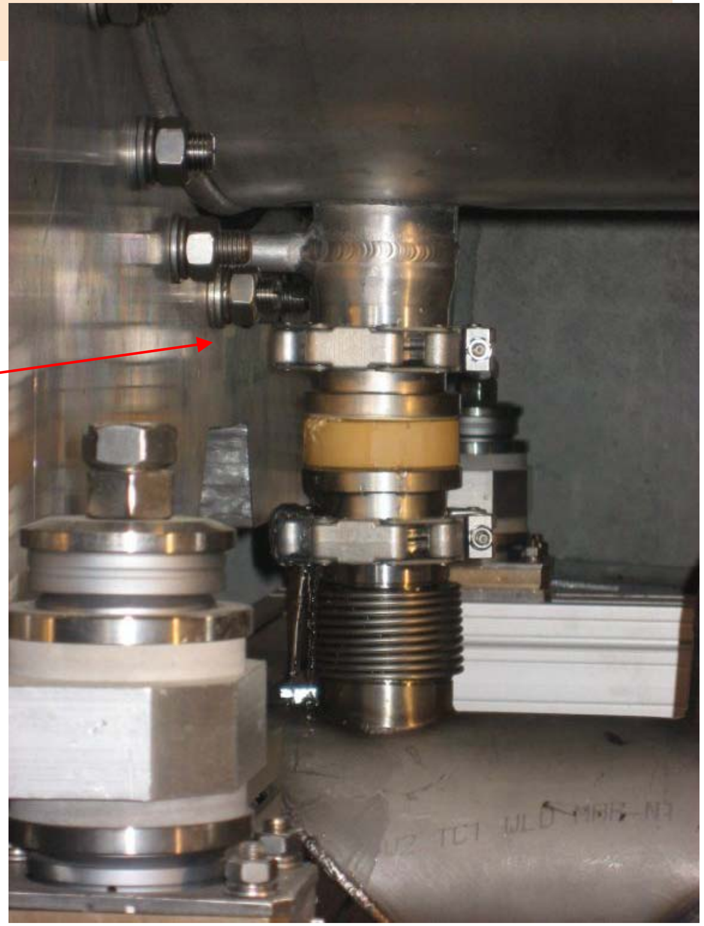
Examples:

- Orientation of accelerator components in order to facilitate the access to the connection boxes at their less-radioactive end.
- Flanges for vacuum pipes which allow for easy coupling/de-coupling.
- Remote bake-out system for critical parts.
- Patch-panels for cables allowing an easier replacement and the use of especially radiation-resistant cables in high-loss areas.
- Use of cables with a radiation resistance of at least 500kGy.
- Placement of ionization chambers (PMI) to monitor remotely residual dose rates at locations with the highest expected losses.
- and….

Examples – CNGS horn water circuit repair

Leak in water outlet of cooling circuit of reflector





Observation:

- High refill rate of closed water circuit of reflector cooling system
- Increased water levels in sumps

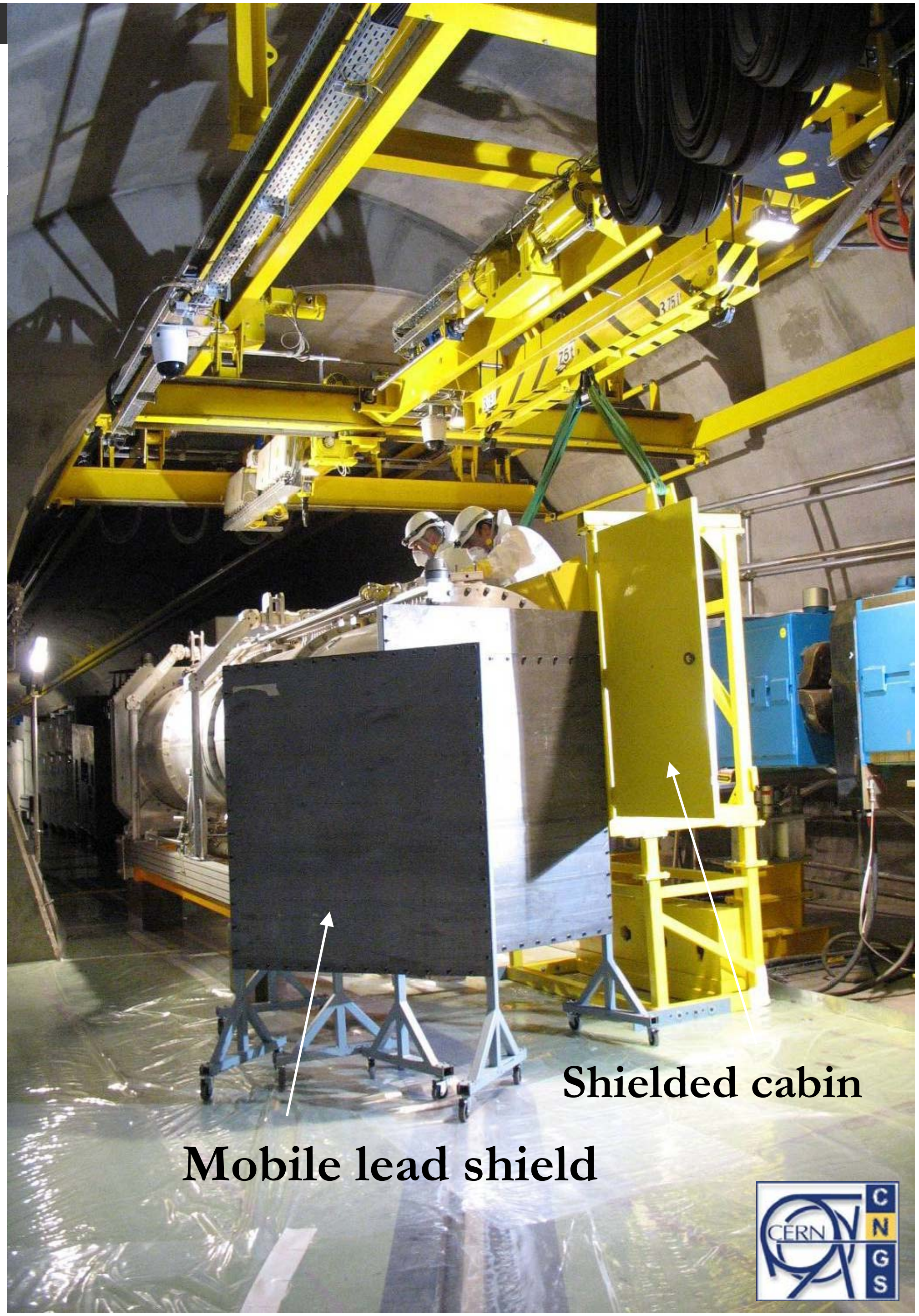
Reason:

- Inadequate design of water outlet connectors (machining, brazing)

Horn and Reflector Repair

→ Repair and exchange
- Detailed radiation dose planning and minimization
- Practice of repair/improvement work on the spare horn in order to reduce exposure time
- Each work step executed by up to 4 persons to reduce individual dose
- Additional local shielding (EN/MEF)

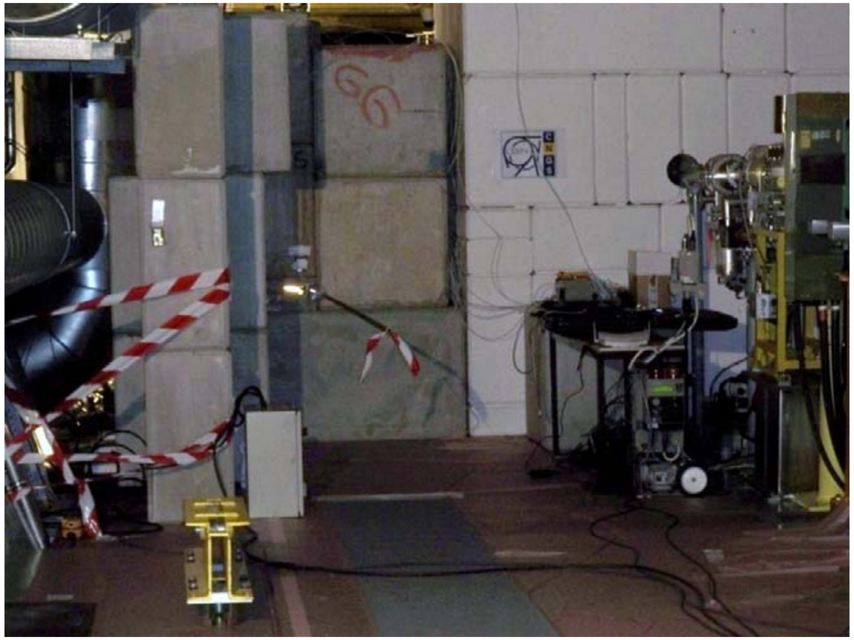
  → total integrated dose: 1.6 mSv

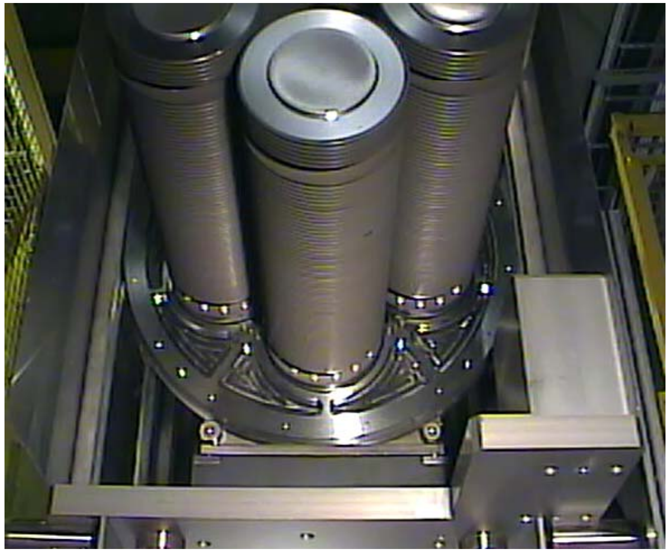


Inspection of the CNGS target

- Dry runs in 867 on spare target
- Installation (in TCC4) of
  - temporary concrete shielding + thick lead glass + plastic cover on the floor
  - remote controlled cameras
  - Motor to rotate the target
- Remote controlled transport of the target
- Inspection done with an endoscope

→ total integrated dose: 287 uSv
(17 persons, dose max 48 uSv)



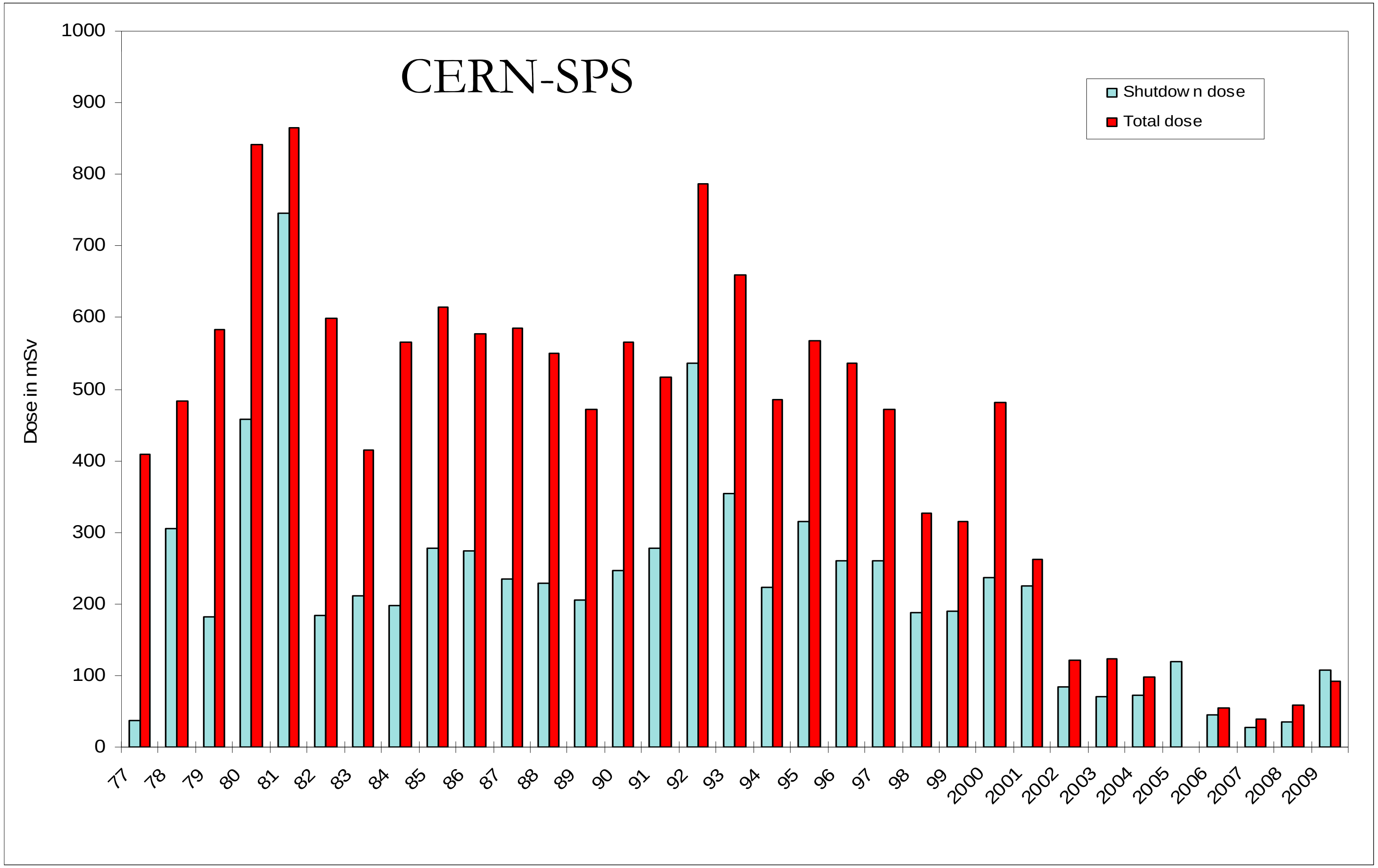


Dismantling of TCX blocks in TCC6

- Modification of a forklift (EN/MEF)
  - Installation of a lead shield and lead glass
  - Design of a new 'fork' (EN/HE)

- If ordering new shielding blocks consider that this forklift can be used for transport.
- Think about modification of existing blocks

ALARA


CERN-SPS
Shutdow n dose
Total dose
Dose in mSv
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2009

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