HSE
Occupational Health & Safety
and Environmental Protection Unit

Radiation Protection aspects

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(on behalf of DGS-RP)

LHC Collimation Review 2011
June 14-15, 2011

Outline

1) Operational scenarios until 2016 (source: M.Lamont)

2) Evolution of dose rates and activation from 2013 until 2016

a) Purely based on run parameters
b) Obtained with generic simulations using actual irradiation profile

3) Radiological situation in Points 3&7 during Long Shutdowns 2013 and 2017

a) LSS3/7 (transport of material and equipment, installation of cables, *etc*.)
b) DS3/7 (modification and installation work)

4) Uncertainties and further verification

5) Summary and conclusions

Operational scenarios for proton runs

Source: M.Lamont 8/6/2011

Year of operation	2010	2011	2012	2014	2015	2016
Number of days physics	39	129	193	120	200	200
Energy (TeV)	3.5	3.5	4.0	6.5	7.0	7.0
Fraction of nominal beam intensity	13%	32%	53%	53%	100%	100%
Peak luminosity ($cm^{-2}s^{-1}$)	1.0×10^{32}	1.0×10^{33}	2.7×10^{33}	5.0×10^{33}	1.0×10^{34}	1.0×10^{34}
Integrated luminosity (fb^{-1})	0.05	4	10.9	9	40.4	40.4

→ rough scaling of activation based on above parameters:

- **scaling with energy** (7TeV / 4TeV): **factor of 1.5** (obtained with generic FLUKA simulations)
- heavy ion run not considered, assuming linear scaling of losses with beam intensity / luminosity, *etc.*

	Activation ratios for shutdowns	2013/2010	2017/2013
beam intensity dependent activation	Short cooling time (scaling w/ beam intensity & energy)	4.1	2.8
	Long cooling time (scaling w/ total number of circulating protons & energy)	29.0	5.7
luminosity dependent activation	Short cooling time (scaling w/ luminosity & energy)	27	5.6
	Long cooling time (scaling w/ integrated luminosity & energy)	300	10.0

more accurate scaling factors for activity → generic study

Generic study

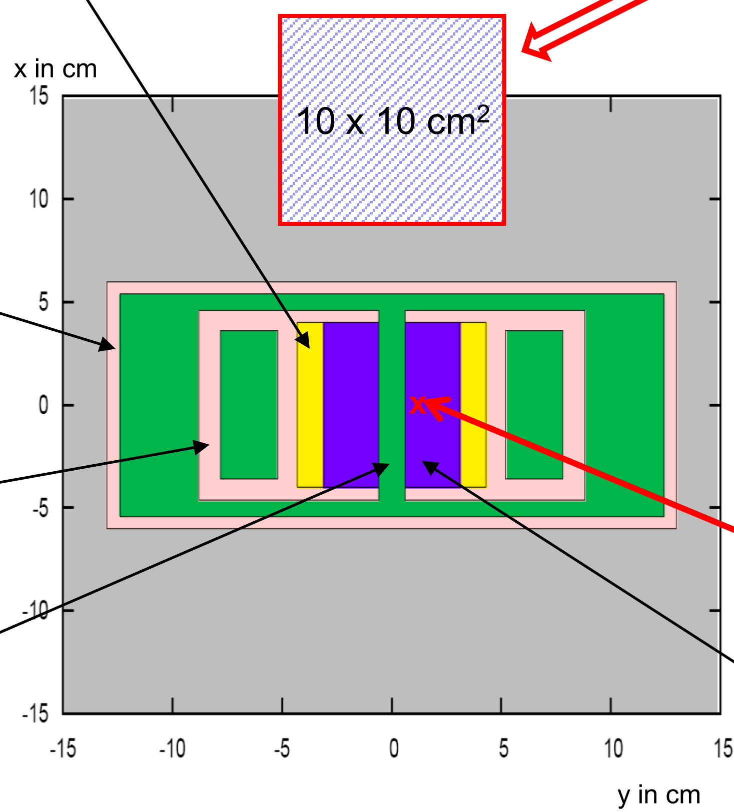
"Collimator" (length: 120 cm)

Cooling system
Copper (scaled density)
15 x 80 mm^2

Tank
Stainless Steel
Thickness: 6 mm

Structure
Stainless Steel
Thickness: 6/10 mm

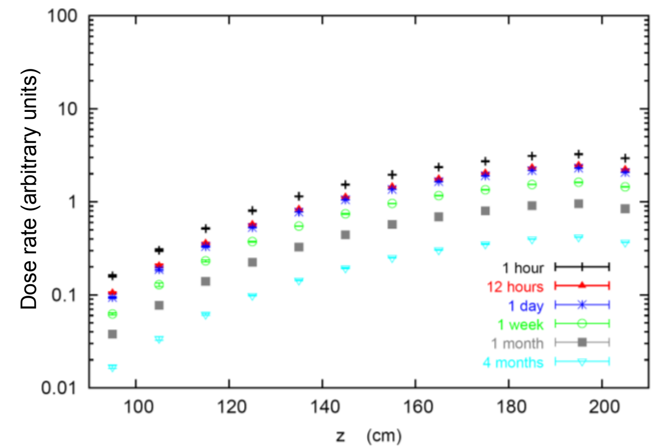
Gap
Full width: 12mm



Jaws
graphite
25 x 80 mm^2

4 TeV protons

Scoring of residual ambient dose equivalent rate at different cooling times
(using actual irradiation profile for 2010-2016):



Dose rate scaling parameters

Evolution of residual dose equivalent rates until 2017
(for areas where activation is related to the beam intensity, *e.g.*, IR3/7)

Dose rate ratios for shutdowns	2013/2010	2017/2013	
Short cooling time	4.1	2.8	scaling w/ beam intensity
One week cooling	6.9	3.1	generic study
One month cooling	9.2	3.2	generic study
Four months cooling	14.9	3.6	generic study
Long cooling time	29	5.7	scaling w/ total number of circulating protons

Dependence on cooling time

Dose rate relative to one month cooling	
One week cooling	1.7
One month cooling	1.0
Four months cooling	0.4

Dose rate predictions – *LSS3*

Dose equivalent rates (µSv/h) (about two months cooling)

IR3-Right	January 2011 (measurement)		January 2013 (Jan.2011 x fac.15)		January 2017 (Jan.2011 x fac.54)	
Element	**Contact**	**Aisle**	**Contact**	**Aisle**	**Contact**	**Aisle**
TCP	13.0	0.3	195.0	4.5	702.0	16.0
TCAPA	24.0	0.7	360.0	11.0	1300.0	38.0
D3	7.0		105.0		380.0	
TCSG.5	7.5	0.2	113.0	3.0	405.0	11.0
MQWA.C	9.0		135.0		490.0	

	Area classification	Dose limit	Ambient dose equivalent rate: At permant workplaces	Ambient dose equivalent rate: In low-occupancy areas
	Non-designated Area	1 mSv / y	< 0.5 µSv h^{-1}	< 2.5 µSv h^{-1}
	Supervised Radiation Area	6 mSv / y	< 3 µSv h^{-1}	< 15 µSv h^{-1}
Controlled Radiation Area	Simple Controlled Radiation Area	20 mSv / y	< 10 µSv h^{-1}	< 50 µSv h^{-1}
	Limited Stay Area			< 2 mSv h^{-1}
	High Radiation Area			<100 mSv h^{-1}
	Prohibited Area			> 100 mSv h^{-1}

- Scaling assumes the IR7/3 loss ratio of the 2010 run
- Possible increased losses from combined momentum/betatron cleaning not included
- Contribution from beam-gas interactions not included (<1µSv/h in aisle, see later)

Dose rate predictions – *LSS7*

Dose equivalent rates (µSv/h) (about two months cooling)

IR7-Right	January 2011 (measurement)		January 2013 (Jan.2011 x fac.15)		January 2017 (Jan.2011 x fac.54)	
Element	**Contact**	**Aisle**	**Contact**	**Aisle**	**Contact**	**Aisle**
TCP.D6	10.0	1.2	150.0	18.0	540.0	65.0
TCP.C6	18.0	2.5	270.0	38.0	970.0	135.0
TCP.B6	31.0	3.1	465.0	47.0	1670.0	170.0
TCAPA	70.0	3.0	1050.0	45.0	3780.0	160.0
TCAPB	13.0	1.2	195.0	18.0	700.0	65.0
TCSG.A6	8.0	1.5	120.0	23.0	430.0	80.0
TCAPC	65.0	2.5	975.0	38.0	3510.0	135.0

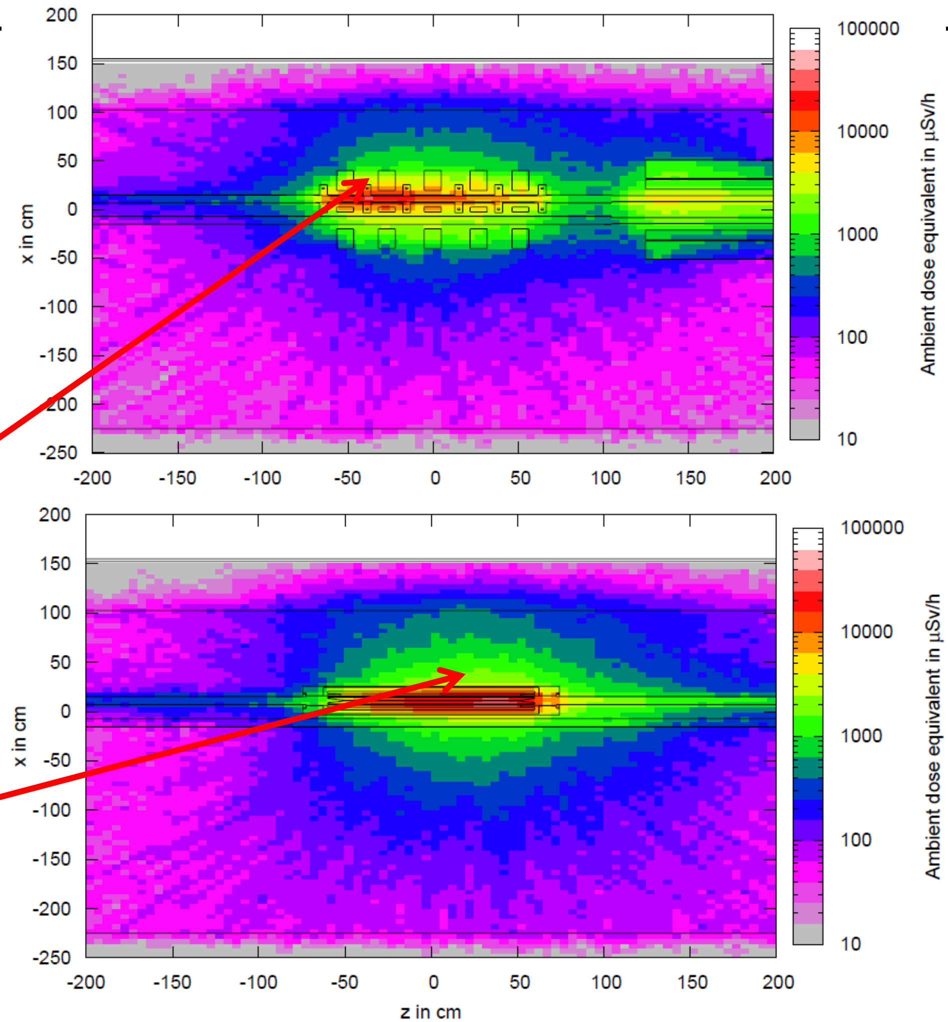
	Area classification	Dose limit	Ambient dose equivalent rate	
			At permant workplaces	In low-occupancy areas
	Non-designated Area	1 mSv / y	< 0.5 µSv h^{-1}	< 2.5 µSv h^{-1}
	Supervised Radiation Area	6 mSv / y	< 3 µSv h^{-1}	< 15 µSv h^{-1}
Controlled Radiation Area	Simple Controlled Radiation Area		< 10 µSv h^{-1}	< 50 µSv h^{-1}
	Limited Stay Area	20 mSv / y		< 2 mSv h^{-1}
	High Radiation Area			<100 mSv h^{-1}
	Prohibited Area			> 100 mSv h^{-1}

Dose rate predictions – *LSS7*

S.Roesler et al., EDMS 863919

Dose equivalent rates (μSv/h)
(about two months cooling)

IR7-Right	January 2017 (Jan.2011 x fac.54)	
Element	Contact	Aisle
TCP.D6	540.0	65.0
TCP.C6	970.0	135.0
TCP.B6	1670.0	170.0
TCAPA	3780.0	160.0
TCAPB	700.0	65.0
TCSG.A6	430.0	80.0
TCAPC	3510.0	135.0

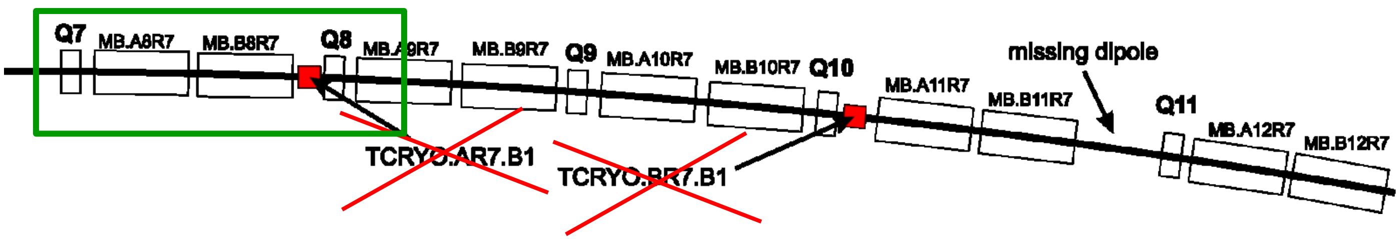


- reasonable agreement for passive absorber
- dose rate somewhat lower than predicted for first secondary collimator (due to present collimator settings?)

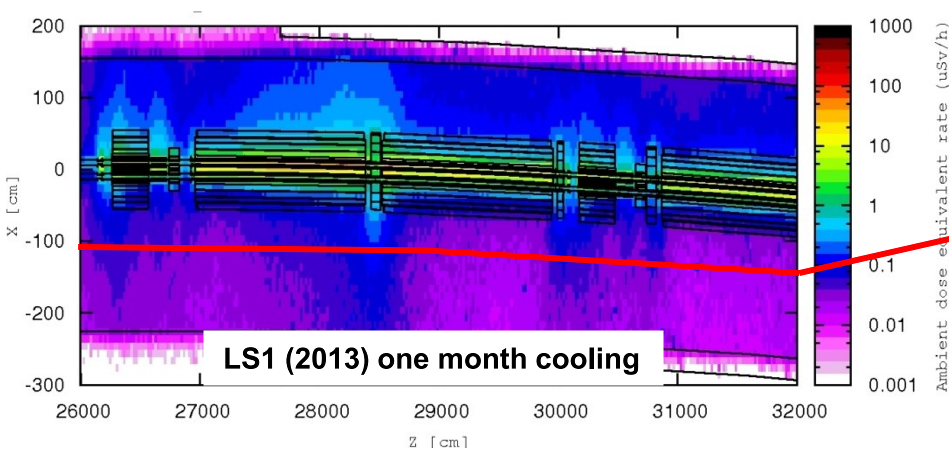
Dose rate predictions – *dispersion suppressors*

Two contributions:

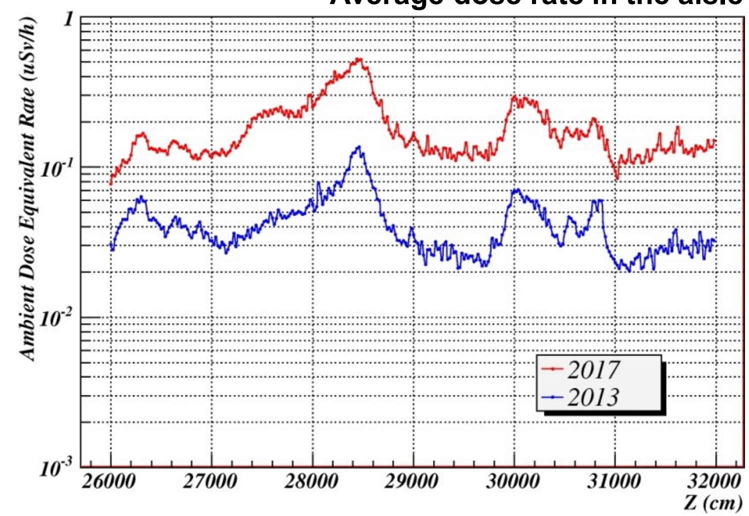
1) Beam-gas interactions



- here: DS at Point 7 (similar for Point 3) assumed BG density: $1{\times}10^{15}$ H_2 eq./m^3
- BG interactions in beam 1 only



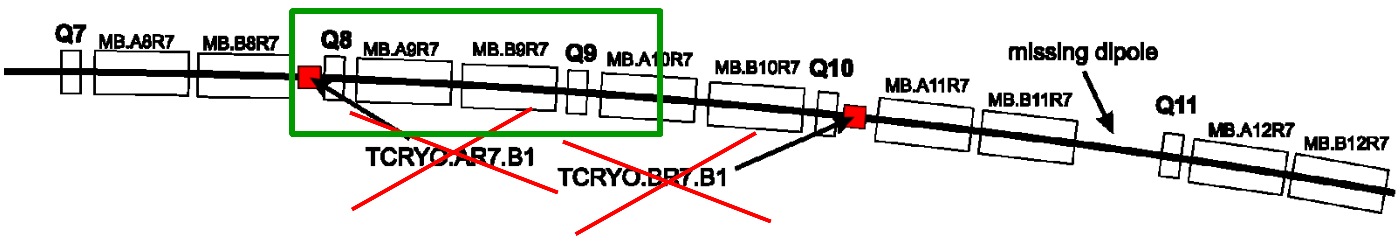
Average dose rate in the aisle



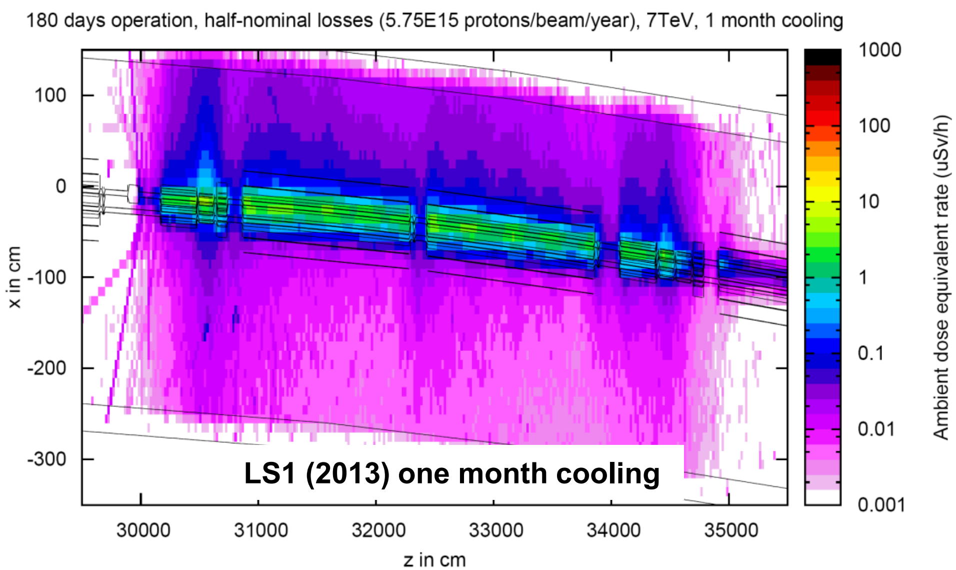
	2013	2017
aisle	< 0.2 μSv/h	< 1 μSv/h
vacuum pipe	< 5 μSv/h	< 20 μSv/h

Dose rate predictions – *dispersion suppressors*

2) Point-losses of protons scattered in the collimators



- here: DS at Point 7 (results existing from Phase II collimation review in 2009 providing envelope for Point 3)



	2013	2017
aisle	< 0.2 µSv/h	< 1 µSv/h
vacuum pipe	< 5 µSv/h	< 20 µSv/h

Uncertainties and verification

Numerous sources of ***uncertainties***:

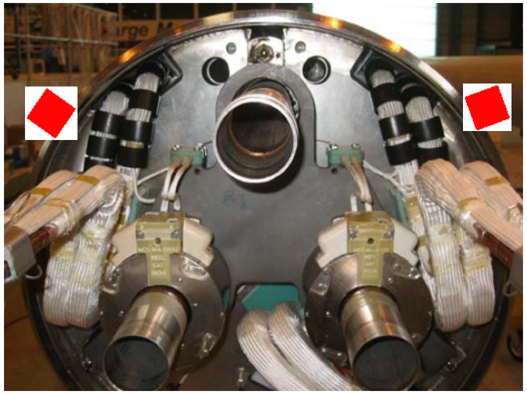
- actual beam-gas pressure
- activation by ion and special runs (scrubbing, MD's, *etc*.)
- loss assumptions (IR3 vs. IR7)
- differences between actual and simulated geometry (collimator settings, imperfections, *etc*.)
- FLUKA models (e.g., for prediction of activation) and simulations (statistical uncertainties)
- ...

→ **Verification by measurements essential**

- survey measurements during technical stops to monitor evolution of residual dose rates
- integrated BLM readings to identify loss points and provide "relative" information
- material samples, especially of materials on which destructive work is foreseen (*e.g*., civil engineering, soldering)

Example: **interconnect consolidation**

- a large number of samples of typical materials (copper, SS, Sn, Ag) have been fixed outside of typical and worst interconnects
- allows monitoring of the evolution of activation



Summary and conclusions - 1

- Based on the operational scenarios for runs 2014-2016, beam intensity-dependent activation and residual dose rates will increase by about a factor of 3-4 from shutdown 2013 until shutdown 2017.

Collimation regions LSS3/7:

- Passage through and work in the area will become more and more restricted (maybe still Simple Controlled Area in 2013, certainly Limited Stay Area in 2017).
- At present, activation in LSS3 is about a factor of 3 lower than in LSS7 (may not be the case anymore if betatron cleaning is moved to IR3).
- Significant risk of contamination for work that requires machining, drilling *etc.* in the area.

Dispersion suppressor areas DS3/7:

- Low/moderate residual dose rates expected for most of the area: few µSv/h in the aisle, <50 µSv/h on beam pipe or components close to it.
- Nevertheless, beam-line components are radioactive - risk of contamination for work that requires machining.

Summary and conclusions - 2

- (Of course) the installation of DS collimators should be performed as early as reasonably possible (ALARA).
- If the installation is postponed to 2017 it is **strongly advised** to prepare it as much as possible, especially to perform all modifications (cabling, *etc.*) that require work in LSS3 (and LSS7?) and any civil engineering (cutting tunnel wall in DS regions) already during 2013.
- Access and transport should avoid passage along collimation region as much as possible. Mobile shielding in front of "hot spots" could relax constraints in this regard.

Additional information
(RP rules and regulations)

RP rules and regulations – *radiological risks*

External exposure

- work in vicinity of activated components
- whole-body dose mostly due to gamma-emitting nuclides
- beta-emitted also contribute to dose to extremities
- legal limits (Radiation workers category B): 6 mSv (whole-body dose)
  150 mSv (extremities)
- design constraint: 2 mSv/intervention/year per person
- compare:

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	-	-	-	-	-

Source: **RP Annual Report 2009**

RP rules and regulations – *radiological risks*

Internal exposure

- machining, welding, soldering of activated components
- dose due to mobile gamma and beta-emitting nuclides
- risk assessment with nuclide-dependent values adapted from Swiss legislation:

Nucléide	Période	Type de désintégration/ de rayonnement	Inhalation e_{inh} Sv/Bq	Ingestion e_{ing} Sv/Bq	Grandeurs d'appréciation h_{10} (mSv/h)/GBq à 1 m de distance	$h_{0,07}$ (mSv/h)/GBq à 10 cm de distance	$h_{c0,07}$ (mSv/h)/(kBq/cm^2)	Limite d'exemption LE Bq/kg ou LE_{abs} Bq	Limite d'autorisation LA Bq	Valeurs directrices CA Bq/m^3	CS Bq/cm^2	Nucléide de filiation instable
1	2	3	4	5	6	7	8	9	10	11	12	13
Co-55	17.54 h	ε, β^+, γ	8.3 E-10	1.1 E-09	0.302	1000	1.4	9 E+03	6 E+06	1 E+04	3	-> Fe-55
Co-56	78.76 d	ε, β^+, γ	4.9 E-09	2.5 E-09	0.485	300	0.6	4 E+03	1 E+06	2 E+03	10	
Co-57	270.9 d	ε, γ	6.0 E-10	2.1 E-10	0.021	100	0.1	5 E+04	8 E+06	1 E+04	100	
Co-58	70.80 d	ε, β^+, γ	1.7 E-09	7.4 E-10	0.147	300	0.3	1 E+04	3 E+06	5 E+03	30	
Co-58m	9.15 h	γ	1.7 E-11	2.4 E-11	<0.001	10	<0.1	4 E+05	3 E+08	5 E+05	1000	-> Co-58 [6]
Co-60	5.271 a	β^-, γ	1.7 E-08	3.4 E-09	0.366	1000	1.1	1 E+03[157]	9 E+04	5 E+02	3	
Co-60m	10.47 m	β^-, γ	1.2 E-12	1.7 E-12	0.001	20	<0.1	6 E+06	4 E+09	7 E+06	300	-> Co-60 [6]
Co-61	1.65 h	β^-, γ	7.5 E-11	7.4 E-11	0.017	1000	1.6	1 E+05	7 E+07	1 E+05	3	
Co-62m	13.91 m	β^-, γ	3.7 E-11	4.7 E-11	0.436	1000	1.8	2 E+05	1 E+08	2 E+05	3	
Ni-56	6.10 d	ε, γ	9.6 E-10	8.6 E-10	0.260	60	0.1	1 E+04	5 E+06	9 E+03	30	-> Co-56 [6]
Ni-57	36.08 h	ε, β^+, γ	7.6 E-10	8.7 E-10	0.278	700	0.8	1 E+04	7 E+06	1 E+04	10	-> Co-57
Ni-59	7.5 E4 a	ε	2.2 E-10	6.3 E-11	<0.001	10	<0.1	2 E+05	2 E+07	4 E+04	1000	
Ni-63	96 a	β^-	5.2 E-10	1.5 E-10	<0.001	<1	<0.1	7 E+04	1 E+07	2 E+04	1000	
Ni-65	2.520 h	β^-, γ	1.3 E-10	1.8 E-10	0.081	1000	1.6	6 E+04	4 E+07	6 E+04	3	
Ni-66 / Cu-66	54.6 h	β^-, γ	1.9 E-09	3.0 E-09	0.039	2000	2.2	3 E+03	3 E+06	4 E+03	3	
Cu-60	23.2 m	ε, β^+, γ	6.2 E-11	7.0 E-11	0.596	1000	1.8	1 E+05	8 E+07	1 E+05	3	
Cu-61	3.408 h	ε, β^+, γ	1.2 E-10	1.2 E-10	0.128	900	1.1	8 E+04	4 E+07	7 E+04	3	
Cu-64	12.701 h	ε, β^+, β^-, γ	1.5 E-10	1.2 E-10	0.030	900	0.8	8 E+04	3 E+07	6 E+04	10	
Cu-67	61.86 h	β^-, γ	5.8 E-10	3.4 E-10	0.018	1000	1.4	3 E+04	9 E+06	1 E+04	3	
Zn-62 / Cu-62	9.26 h	ε, β^+, γ	6.6 E-10	9.4 E-10	0.319	1000	1.9	1 E+04	8 E+06	1 E+04	3	
Zn-63	38.1 m	ε, β^+, γ	6.1 E-11	7.9 E-11	0.175	1000	1.6	1 E+05	8 E+07	1 E+05	3	
Zn-65	243.9 d	ε, β^+, γ	2.8 E-09	3.9 E-09	0.086	40	0.1	3 E+03	2 E+06	3 E+03	30	
Zn-69	57 m	β^-, γ	4.3 E-11	3.1 E-11	<0.001	1000	1.6	3 E+05	1 E+08	2 E+05	3	

Source: **ORaP, Swiss legislation**

RP rules and regulations – *ALARA*

Optimization is a legal requirement if accumulated individual dose exceeds 100 µSv/year (ALARA)

CRITÈRE DE DÉBIT DE DOSE

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

niveau I	50 µSv·h^{-1}	niveau II	2 mSv·h^{-1}	niveau III

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	100 µSv	niveau II	1 mSv	niveau III

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	500 µSv	niveau II	10 mSv	niveau III

CRITÈRE DE CONTAMINATION ATMOSPHÉRIQUE

Activité aérienne spécifique CA :

niveau I	5 CA	niveau II	200 CA	niveau III

CRITÈRE DE CONTAMINATION SURFACIQUE

Activité surfacique spécifique CA :

niveau I	10 CS	niveau II	100 CS	niveau III

Note: 1 Sv = 100 rem

Optimization includes

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

	Type d'intervention	répétitives / génériques			ponctuels / unitaires		
	Niveau de risque	I	II	III	I	II	III
	Dosimétrie individuelle	●	●	●	●	●	●
	Dosimétrie opérationnelle sans alarme	●			●		
	Dosimétrie opérationnelle avec alarme		●	●		●	●
Dossier de sécurité	Docts. descriptifs		○	○			○
	Docts. justificatifs		○	●			●
	Docts. d'exploitation		○	○			○
	Analyse de risques radiologiques	●	●	●	●	●	●
	Calculs radiologiques / codes simples			●			●
	Calculs radiologiques / codes élaborés			●			●
	Justification par analyses multi-critères		○	●		○	○
	Prise en compte du retour d'expérience	●	●	●	●	●	●
Dossier d'intervention en milieu radioactif	DIMR de niveau I	●			●		
	DIMR de niveau II		●			●	
	DIMR de niveau III			●			●
	Cartographie dosimétrique	○	●	●	○	●	●
	Relevé de décisions du comité ALARA			●			○
	Fiche d'écart / Retour d'expérience	○	○	○	○	○	○

- ● required
- ○ optional

RP rules and regulations – *area classification*

Tableau 4 — Résumés des critères de classification des zones non règlementée et radiologiques règlementées du CERN.

Radiation Areas

Classification de la zone	Limite de dose	Débit d'équivalent de dose maximal – Zone de travail	Débit d'équivalent de dose maximal – Zone de passage	Contamination atmosphérique volumique	Contamination surfacique spécifique	Catégories de travailleurs autorisés à accéder à la zone	Dosimétrie requise
Zone non règlementée	1 mSv·an^{-1}	< 0,5 µSv·h^{-1}	< 2,5 µSv·h^{-1}	-	-	Toutes	Aucune dosimétrie requise
Zone radiologique surveillée	6 mSv·an^{-1}	< 3 µSv·h^{-1}	< 15 µSv·h^{-1}	-	-	Catégorie **A** Catégorie **B** Catégorie **C** (VCT)	Dosimètre personnel
Zone radiologique contrôlée – Zone contrôlée simple	20 mSv·an^{-1}	< 10 µSv·h^{-1}	< 50 µSv·h^{-1}	-	-	Catégorie **A** Catégorie **B***	Dosimètres personnel **et** dosimétries opérationnelles**
Zone radiologique contrôlée – Zone de séjour limité			< 2 mSv·h^{-1}	< 100 CA	< 4000 CS	Catégorie **A*** Catégorie **B***	Dosimètres personnel **et** dosimétries opérationnelles
Zone radiologique contrôlée – Zone de haute activité			< 100 mSv·h^{-1}	< 1000 CA	< 40'000 CS	Catégorie **A*** Catégorie **B***	
Zone radiologique contrôlée – Zone interdite			> 100 mSv·h^{-1}	< 1000 CA	> 40'000 CS	Aucune	

* La présence en Zones contrôlées des travailleurs de catégories A et B est limitée pour garantir le non dépassement des limites règlementaires.

Note: 1 mSv = 100 mrem

RP rules and regulations – *radioactive material*

Radioactive = specific ***and*** total activities exceed LE

or dose rate at 10cm distance >10 μSv/h

Mixture of nuclides: $$\sum_{i=1}^{n} \frac{a_i}{LE_i} > 1$$

LE values:
ingestion of activity LE leads to a dose of 10 μSv

Nucléide	Période	Type de désintégra-tion/ de rayonnement	e_{inh} Sv/Bq	e_{ing} Sv/Bq	Grandeurs d'appréciation: h_{10} (mSv/h)/GBq à 1 m de distance	$h_{0,07}$ (mSv/h)/GBq à 10 cm de distance	$h_{c0,07}$ (mSv/h)/ (kBq/cm^2)	Limite d'exemp-tion: LE Bq/kg ou LE_{abs} Bq	Limite d'auto-risation: LA Bq	Valeurs directrices: CA Bq/m^3	CS Bq/cm^2	Nucléide de filiation instable
1	2	3	4	5	6	7	8	9	10	11	12	13
Co-55	17.54 h	$\varepsilon, \beta^+, \gamma$	8.3 E-10	1.1 E-09	0.302	1000	1.4	9 E+03	6 E+06	1 E+04	3	-> Fe-55
Co-56	78.76 d	$\varepsilon, \beta^+, \gamma$	4.9 E-09	2.5 E-09	0.485	300	0.6	4 E+03	1 E+06	2 E+03	10	
Co-57	270.9 d	ε, γ	6.0 E-10	2.1 E-10	0.021	100	0.1	5 E+04	8 E+06	1 E+04	100	
Co-58	70.80 d	$\varepsilon, \beta^+, \gamma$	1.7 E-09	7.4 E-10	0.147	300	0.3	1 E+04	3 E+06	5 E+03	30	
Co-58m	9.15 h	γ	1.7 E-11	2.4 E-11	<0.001	10	<0.1	4 E+05	3 E+08	5 E+05	1000	-> Co-58 [6]
Co-60	5.271 a	β^-, γ	1.7 E-08	3.4 E-09	0.366	1000	1.1	1 E+03[17]	9 E+04	5 E+02	3	
Co-60m	10.47 m	β^-, γ	1.2 E-12	1.7 E-12	0.001	20	<0.1	6 E+06	4 E+09	7 E+06	300	-> Co-60 [6]
Co-61	1.65 h	β^-, γ	7.5 E-11	7.4 E-11	0.017	1000	1.6	1 E+05	7 E+07	1 E+05	3	
Co-62m	13.91 m	β^-, γ	3.7 E-11	4.7 E-11	0.436	1000	1.8	2 E+05	1 E+08	2 E+05	3	
Ni-56	6.10 d	ε, γ	9.6 E-10	8.6 E-10	0.260	60	0.1	1 E+04	5 E+06	9 E+03	30	-> Co-56 [6]
Ni-57	36.08 h	$\varepsilon, \beta^+, \gamma$	7.6 E-10	8.7 E-10	0.278	700	0.8	1 E+04	7 E+06	1 E+04	10	-> Co-57
Ni-59	7.5 E4 a	ε	2.2 E-10	6.3 E-11	<0.001	10	<0.1	2 E+05	2 E+07	4 E+04	1000	
Ni-63	96 a	β^-	5.2 E-10	1.5 E-10	<0.001	<1	<0.1	7 E+04	1 E+07	2 E+04	1000	
Ni-65	2.520 h	β^-, γ	1.3 E-10	1.8 E-10	0.081	1000	1.6	6 E+04	4 E+07	6 E+04	3	
Ni-66 / Cu-66	54.6 h	β^-, γ	1.9 E-09	3.0 E-09	0.039	2000	2.2	3 E+03	3 E+06	4 E+03	3	
Cu-60	23.2 m	$\varepsilon, \beta^+, \gamma$	6.2 E-11	7.0 E-11	0.596	1000	1.8	1 E+05	8 E+07	1 E+05	3	
Cu-61	3.408 h	$\varepsilon, \beta^+, \gamma$	1.2 E-10	1.2 E-10	0.128	900	1.1	8 E+04	4 E+07	7 E+04	3	
Cu-64	12.701 h	$\varepsilon, \beta^+, \beta^-, \gamma$	1.5 E-10	1.2 E-10	0.030	900	0.8	8 E+04	3 E+07	6 E+04	10	
Cu-67	61.86 h	β^-, γ	5.8 E-10	3.4 E-10	0.018	1000	1.4	3 E+04	9 E+06	1 E+04	3	
Zn-62 / Cu-62	9.26 h	$\varepsilon, \beta^+, \gamma$	6.6 E-10	9.4 E-10	0.319	1000	1.9	1 E+04	8 E+06	1 E+04	3	
Zn-63	38.1 m	$\varepsilon, \beta^+, \gamma$	6.1 E-11	7.9 E-11	0.175	1000	1.6	1 E+05	8 E+07	1 E+05	3	
Zn-65	243.9 d	$\varepsilon, \beta^+, \gamma$	2.8 E-09	3.9 E-09	0.086	40	0.1	3 E+03	2 E+06	3 E+03	30	
Zn-69	57 m	β^-, γ	4.3 E-11	3.1 E-11	<0.001	1000	1.6	3 E+05	1 E+08	2 E+05	3	

Source: **ORaP, Swiss legislation**