Best Practices for ALARA

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on behalf of DGS-RP

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HSE
Occupational Health & Safety
and Environmental Protection Unit

High Luminosity LHC

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Outline

1. Reminder – legal constraints
   - Limitation
   - Optimization / ALARA
   - Radiological quantities to be assessed
2. Optimization during design
   - Design criteria
   - Methodology
   - Example (LHC collimators)
   - Design options for ALARA
   - Optimizing material selection (ActiWiz)
3. Dose rate outlook until 2035
   - Operational scenario
   - LS1 & comparison with measurements
   - Evolution until LS3
   - Predictions for HL-LHC until 2035

Safety Code F – *Limitation*

Design and operation !

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 / yr**

Category B: **6 mSv / yr**

Others

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 / yr

Environment

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 / yr

Safety Code F – *Limitation*

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

- Total number of working hours per year: 2000 hours
  (*example:* Supervised Area 3 µSv/h × 2000 h = 6 mSv)

- Low-occupancy: < 20% of working time

Safety Code F – *Optimization (ALARA)*

Design and operation !

2.3 Optimisation

2.3.1 The principle of optimisation of radiation protection is defined as a process to keep the magnitude of individual doses and the number of people exposed As Low As Reasonably Achievable (ALARA) below the appropriate dose limits, economic and social factors being taken into account.

2.3.2 ALARA must be applied by means of optimisation, which is the balancing of constraints on individual doses, risks, number of persons involved, cost of protection measures and consequences of potential failures.

2.3.3 A practice is considered as optimised when:

a) Different appropriate measures have been evaluated and judged against each other from the radiation protection viewpoint,

b) The decisional process leading to the chosen solution is documented,

c) The risk of failures has been taken into account and

d) The long-term consequences for activated material (re-use or final disposal) have been properly managed.

2.3.4 Optimisation can be considered as respected if the practice never gives rise to an annual dose above 100 μSv for persons exposed because of their own professional activity or 10 μSv for circumstances not linked with their own professional activity and for members of the general public.

Workers on CERN site
100 μSv / yr
Outside of CERN (environment)
10 μSv / yr

Safety Code F – *Limitation* / *Optimization*

	On CERN sites		Outside of CERN
	Radiation Workers	Other Workers	Population
Limits	**6 / 20 mSv / yr**	**1 mSv /yr**	**300 µSv / yr**

Optimization / ALARA to be demonstrated

Optimization thresholds	**100 µSv / yr**	**100 µSv / yr**	**10 µSv / yr**

Optimized (by definition)

Radiological quantities

1. Periods of beam operation

   - dose equivalent to personnel by stray radiation in accessible areas
     (*example: dose in counting rooms of LHC experiments during operation)*

   - activation of effluents and air and their release into the environment as well as the resulting annual dose to the reference groups of the population
     (*example: dose to reference group in the vicinity of LHC Point 1 after LS3)*

   - dose equivalent to personnel and environment in case of abnormal operation or accidents
     (*examples: dose in counting rooms of LHC experiments during full beam loss, dose impact of fire)*

2. Beam-off periods

   - radioactivity induced by beam losses in beam-line components and related residual dose equivalent rates *(example: dose equivalent rate maps in the UX and LSS)*

   - individual and collective doses to personnel during interventions on activated beam-line components or experiments (*example: predictions of individual and collective dose for magnet exchange)*

3. Decommissioning

   - radionuclide inventory for waste disposal

Optimization during design

	On CERN sites: Radiation Workers	On CERN sites: Other Workers	Outside of CERN: Population
Limits	**6 / 20 mSv / yr**	**1 mSv /yr**	**300 µSv / yr**
Optimization thresholds	**100 µSv / yr**	**100 µSv / yr**	**10 µSv / yr**

Prompt radiation:
Dose equivalent to personnel involved in activity of the area

Residual radiation:
Individual and collective doses to personnel during interventions
Design criterion: 2 mSv/intervention/year

Prompt radiation:
Annual dose to personnel not involved in activity of the area

Prompt and residual radiation:
Annual dose to reference group of population

Intervention doses – *Methodology*

1. Calculation of residual dose rate maps
   - for cooling times typical for interventions on the respective component
   - based on nominal operational parameters
   - definition of geometry and materials as detailed as needed (and available)

2. Calculation of individual and collective intervention doses
   - based on as realistic as possible work scenarios, including locations, duration, number of persons involved,..
   - identification of cooling times below which work will be impossible (design criterion: 2 mSv/intervention/year)
   - communication of results and constraints to equipment groups

3. Revision of design and/or work scenario
   - start with work steps that give highest individual or collective doses
   - consider optimization measures (distance, tooling, material choices, *etc.*)
   - identify if remote handling is possible

Start of iteration:

New design ? → Step 1
Revised work scenario ? → Step 2

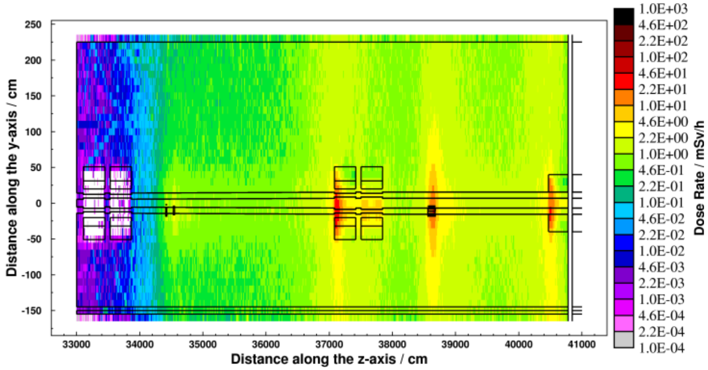
Intervention doses – *Example: LHC collimators*

Cooling time

Residual dose rate (mSv/h) after one year of operation at nominal intensity

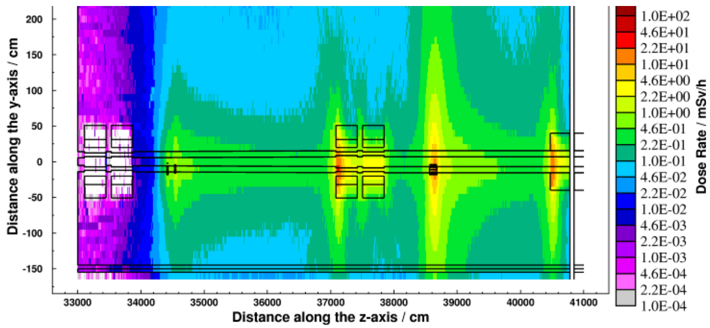
8 hours

Aisle: 0.5-2mSv/h
Close: 2-20mSv/h



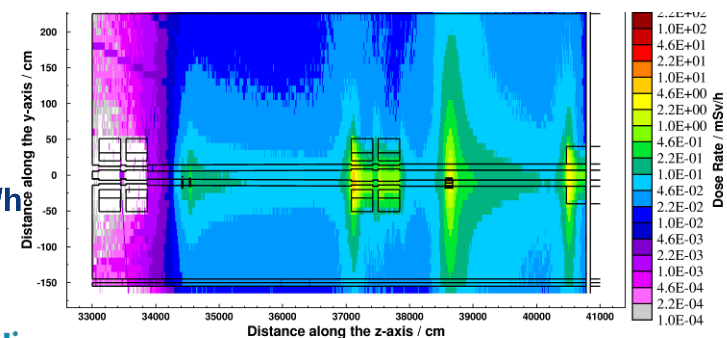
1 week

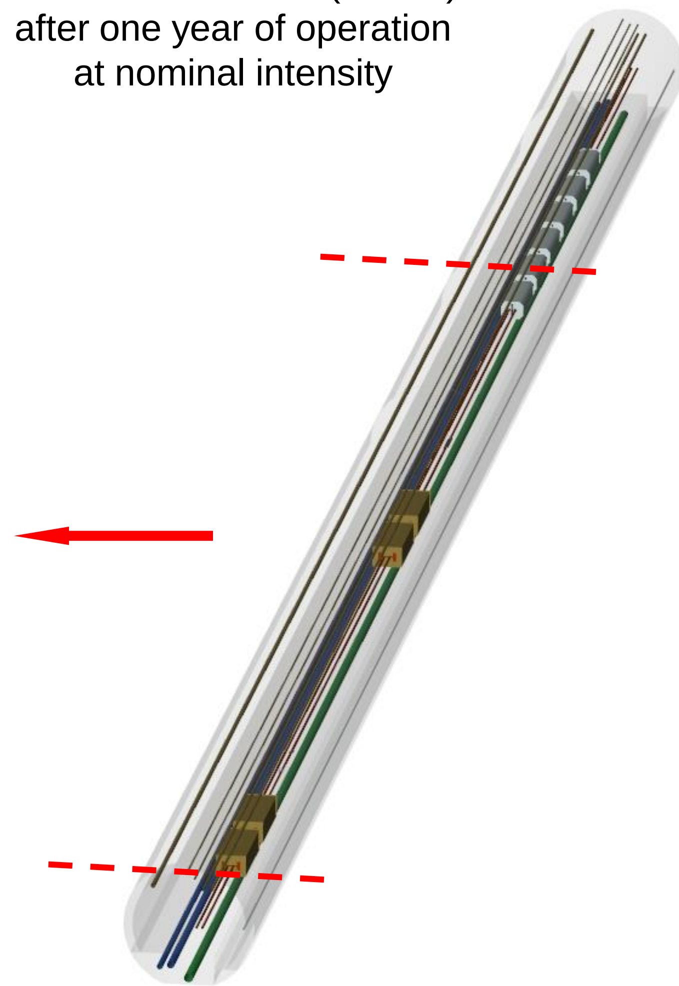
Aisle: 0.1-0.5mSv/h
Close: 0.5-5mSv/h



4 months

Aisle: 0.01-0.1mSv/h
Close: 0.1-1mSv/h





Intervention doses – *Example: LHC collimators*

1. Work by collimation team

Exchange of a Collimator - People Intervening on the Collimator only								
Actions	Time per person	Individual Dose / Person [mSv]						# of Persons
		1h	8h	1d	1w	1m	4m	
Transport material	10	0.129	0.084	0.045	0.010	0.006	0.003	2
Close manual water valve	1	0.063	0.041	0.034	0.020	0.010	0.005	1
Connect water circuit to pressurized air	1	0.063	0.041	0.034	0.020	0.010	0.005	1
Purge water circuit with air	5	0.232	0.136	0.085	0.032	0.020	0.010	1
Position transport material	2	0.117	0.073	0.057	0.030	0.017	0.007	1
Fix lifting equipment to collimator tank	3	0.375	0.304	0.239	0.153	0.086	0.035	2
Lift the collimator	2	0.125	0.082	0.068	0.040	0.021	0.010	1
place the collimator on the transport unit	2	0.117	0.073	0.057	0.030	0.017	0.007	1
Move the faulty collimator	1	0.046	0.027	0.017	0.006	0.004	0.002	1
Position replacement collimator	1	0.059	0.036	0.028	0.015	0.008	0.003	1
Fix lifting equipment to collimator tank	3	0.176	0.109	0.085	0.045	0.025	0.010	2
Lift the collimator	2	0.135	0.096	0.077	0.042	0.024	0.010	1
Install the collimator with quick plug in	5	0.625	0.506	0.398	0.254	0.143	0.058	2
Check electrical connections	2	0.250	0.202	0.159	0.102	0.057	0.023	1
Open manual water valve	1	0.063	0.041	0.034	0.020	0.010	0.005	1
Check water connections, flow	2	0.125	0.082	0.068	0.040	0.021	0.010	1
Other Person Waiting	22	1.287	0.799	0.623	0.329	0.183	0.077	1
Transport out of material	10	0.129	0.084	0.045	0.010	0.006	0.003	2
1st Person	**53**	**2.7**	**1.9**	**1.4**	**0.8**	**0.5**	**0.2**	
2nd Person	**53**	**2.8**	**2.0**	**1.5**	**0.9**	**0.5**	**0.2**	
Collective Dose	**106**	**5.5**	**3.9**	**3.0**	**1.7**	**0.9**	**0.4**	

Intervention doses – *Example: LHC collimators*

2. Work by vacuum team

Intervention	Duration / min	Accumulated Dose (mSv)					
		1h	8h	1d	1w	1m	4m
CF flanges with bolts							
Collimator exchange (leak)	180	6.2	4.3	3.1	1.5	0.8	0.4
Collimator exchange (failure)	155	5.1	3.5	2.6	1.2	0.7	0.3
Dismounting of 2nd beam-line	150	4.9	3.3	2.4	1.1	0.6	0.3
CF flanges with chain clamps							
Collimator exchange (leak)	136	4.1	2.9	2.0	0.9	0.5	0.2
Collimator exchange (failure)	111	3.1	2.1	1.5	0.6	0.4	0.2
Dismounting of 2nd beam-line	106	2.8	1.9	1.4	0.6	0.3	0.2

→ using vacuum connections with chain clamps reduces the individual dose by almost 40%

Additional dose for the bake out of a single vacuum Sector in IR7

Actions	Time per person	Accumulated Dose / Person [mSv/person]					
		1h	8h	1d	1w	1m	4m
Transportation of the material (tooling box, and	20	0.258	0.168	0.090	0.020	0.013	0.006
Checking of the thermocouplers (~72 permanently	15	0.590	0.428	0.280	0.124	0.075	0.032
Installation of heating jackets	220	8.653	6.270	4.107	1.815	1.096	0.473
Bake out follow up		0.000	0.000	0.000	0.000	0.000	0.000
Using the existing controllers	20	0.787	0.570	0.373	0.165	0.100	0.043
Using the new design PLC controllers							
Conditioning of the vacuum instrumentation and	15	0.590	0.428	0.280	0.124	0.075	0.032
Disconnection of the bake out, bake out removal	50	1.967	1.425	0.933	0.413	0.249	0.108
Transportation of the material (tooling box and	20	0.258	0.168	0.090	0.020	0.013	0.006
Not Permanent	**360**	**13.1**	**9.5**	**6.2**	**2.7**	**1.6**	**0.7**
Permanent	**90**	**2.5**	**1.8**	**1.1**	**0.5**	**0.3**	**0.1**
Collective Dose [mSv]							
Not Permanent		**26.2**	**18.9**	**12.3**	**5.4**	**3.2**	**1.4**
Permanent		**5.0**	**3.5**	**2.2**	**0.9**	**0.5**	**0.2**

→ a permanent bake-out equipment lowers the individual and collective dose by a factor of five

Intervention doses – *Example: LHC collimators*

4. Summary of work of all involved groups

Actions	Individual Dose / mSv							Collective Dose / mSv						
	Time	1h	8h	1d	1w	1m	4m	Number	1h	8h	1d	1w	1m	4m
Collimator Exchange (Collimator)														
Collimator exchange (old scenario!)	74	4.8	3.4	2.7	1.6	0.9	0.4	2	9.5	6.9	5.4	3.2	1.8	0.8
Collimator exchange (new scenario!) 1st person	53	2.7	1.9	1.4	0.8	0.5	0.2	1-2	5.5	3.9	3.0	1.7	0.9	0.4
Collimator exchange (new scenario!) 2nd person	53	2.8	2.0	1.5	0.9	0.5	0.2							
Vacuum Intervention (CF flanges with bolts)														
Collimator exchange (due to a failure)	155	5.1	3.5	2.6	1.2	0.7	0.3	2	12.3	8.5	6.2	2.9	1.7	0.7
Dismounting of 2nd beam-line	150	4.9	3.3	2.4	1.1	0.6	0.3	2	9.7	6.6	4.9	2.3	1.3	0.6
Vacuum Intervention (CF flanges with chain clamps)														
Collimator exchange (due to a failure)	111	3.1	2.1	1.5	0.6	0.4	0.2	2	10.2	7.0	5.1	2.4	1.4	0.6
Dismounting of 2nd beam-line	106	2.8	1.9	1.4	0.6	0.3	0.2	2	9.7	6.6	4.9	2.3	1.3	0.6
Vacuum Intervention - Bakeout (different work group)														
not permanent	360	13.1	9.5	6.2	2.7	1.6	0.7	2	26.2	18.9	12.3	5.4	3.2	1.4
permanent	90	2.5	1.8	1.1	0.5	0.3	0.1	2	5.0	3.5	2.2	0.9	0.5	0.2
Radiation Protection (Estimate as getting half of the dose of one person participating in each step)														
Collimator exchange	53	1.4	0.9	0.7	0.4	0.2	0.1	1	1.4	0.9	0.7	0.4	0.2	0.1
1st Vacuum Intervention - bolts	155	2.6	1.7	1.3	0.6	0.3	0.2	1	2.6	1.7	1.3	0.6	0.3	0.2
1st Vacuum Intervention (2nd b.)- bolts	150	2.4	1.7	1.2	0.6	0.3	0.1	1	2.4	1.7	1.2	0.6	0.3	0.1
1st Vacuum Intervention - chain cl.	111	1.5	1.1	0.8	0.3	0.2	0.1	1	1.5	1.1	0.8	0.3	0.2	0.1
1st Vacuum Intervention (2nd b.)- ch.cl.	106	1.4	1.0	0.7	0.3	0.2	0.1	1	1.4	1.0	0.7	0.3	0.2	0.1
during bakeout (not permanent)	360	6.6	4.7	3.1	1.3	0.8	0.3	1	6.6	4.7	3.1	1.3	0.8	0.3
during bakeout (permanent)	90	1.2	0.9	0.6	0.2	0.1	0.1	1	1.2	0.9	0.6	0.2	0.1	0.1

Conclusions:

- minimum waiting time at least one week
- use of quick-connect flanges necessary
- installation of permanent bake-out equipment is important

Optimization during design – *Design Options*

1. Material choice

    - Low activation properties to reduce residual doses and minimize radioactive waste (optimization with ActiWiz code, see below)
    - Avoid materials for which no radioactive waste elimination pathway exists (e.g., highly flammable metallic activated waste)
    - Radiation resistant

2. Optimized handling

    - Easy access to components that need manual intervention (e.g., valves, electrical connectors) or complex manipulation (e.g., cables)
    - Provisions for fast installation/maintenance/repair, in particular, around beam loss areas (*e.g.,* plugin systems, quick-connect flanges, remote survey, remote bake-out)
    - Foresee easy dismantling of components

3. Limitation of installed material

    - Install only components that are absolutely necessary, in particular in beam loss areas
    - Reduction of radioactive waste

Optimization during design – *Material choice*

Goal:
- Minimize doses received by personnel during maintenance and repair
- Reduce downtime due to faster access and less restrictions for manipulation
- Reduce costs for waste disposal

➔ Consider radiological hazards in the choice of construction materials

Tool to optimize material choices:

ActiWiz

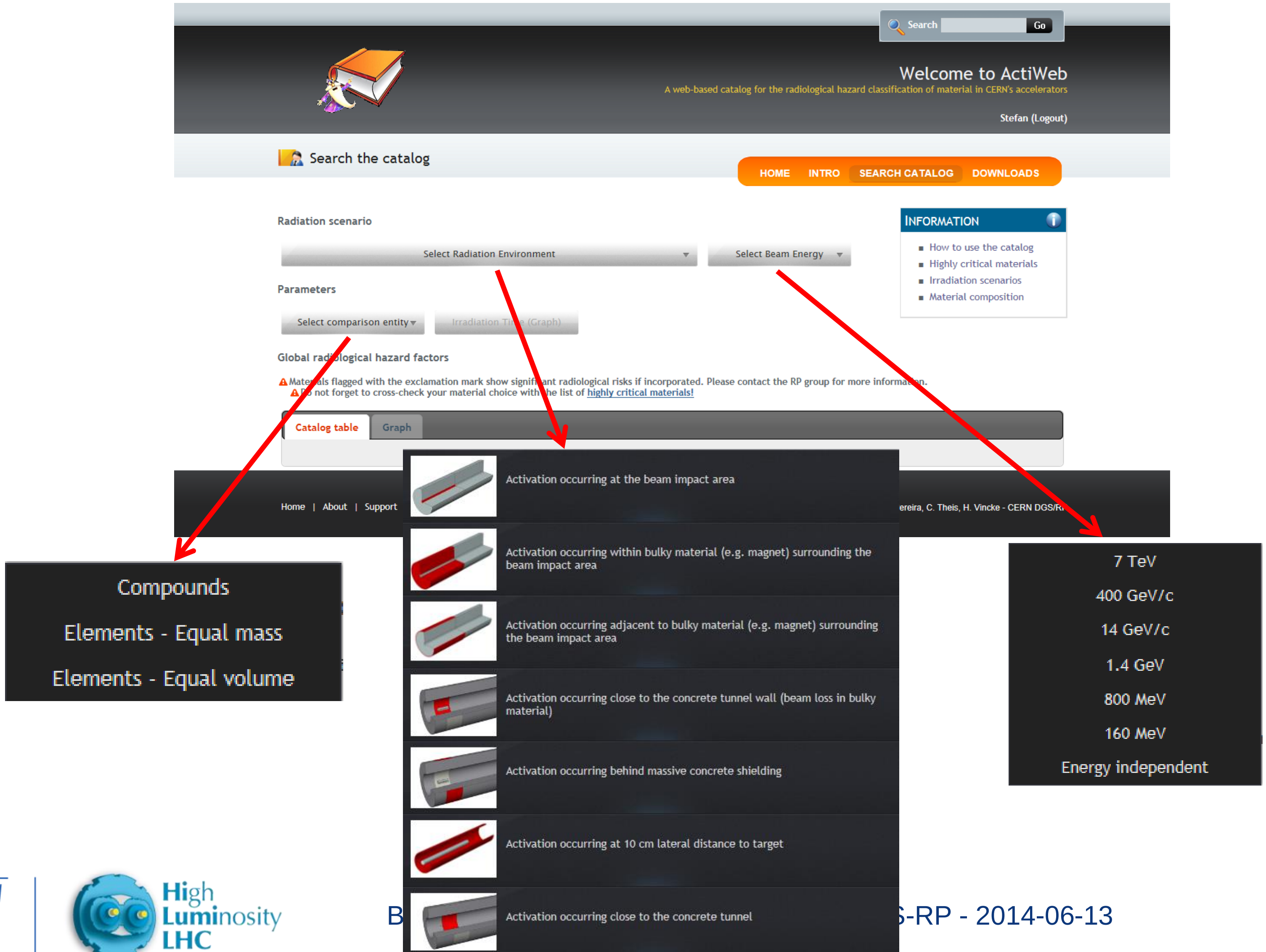
(Authors: **C.Theis and Helmut Vincke**)

- Computer code based on a risk model using pre-calculated FLUKA results. Considers external exposure and radioactive waste disposal
- Provides radiological hazard assessment for arbitrary materials within a few seconds
- Catalogue, produced with ActiWiz, listing pre-processed risk factors for typical accelerator construction materials as well as natural elements
- Web-based catalogue (ActiWeb) allowing user friendly comparison of pre-processed materials

Materials not available in the catalogue can be processed with ActiWiz

Web-site: https://actiwiz.web.cern.ch/

Optimization during design – *ActiWiz*



Optimization during design – *ActiWiz*

Catalog table | Graph

Compound	1 day		1 week		1 op. year (200d)		20 years (20 x 365d)		independent average	
	Operational	Waste	Operational	Waste	Operational	Waste	Operational	Waste	Operational	Waste
Aluminium_2219	0.51	0.58	0.24	0.58	0.16	0.56	0.43	0.41	0.28	0.51
Aluminium_5083	0.50	0.43	0.23	0.43	0.14	0.41	0.43	0.29	0.27	0.37
Aluminium_6060	0.50	0.41	0.23	0.40	0.13	0.39	0.40	0.28	0.25	0.36
Aluminium_6061	0.50	0.41	0.23	0.41	0.13	0.40	0.40	0.28	0.25	0.36
Aluminium_6082	0.49	0.41	0.23	0.41	0.13	0.39	0.41	0.28	0.26	0.36
Aluminium_ALUMAN	0.50	0.40	0.23	0.40	0.14	0.39	0.41	0.28	0.26	0.36
Aluminium_PERALU	0.49	0.42	0.23	0.42	0.14	0.40	0.41	0.28	0.26	0.37
Brass_CuZn37	0.76	2.48	0.79	2.48	1.42	2.43	1.86	1.93	1.35	2.28
Brass_CuZn39Pb3	0.80	2.47	0.82	2.47	1.41	2.42	1.83	2.05	1.35	2.31
Concrete_Barite	0.26	4.01	0.24	4.01	0.20	4.02	0.33	5.71	0.26	4.58
Concrete_BaronBarite	0.24	3.91	0.21	3.91	0.17	3.91	0.29	5.56	0.22	4.46
Concrete_CERF	4.45e-2	0.23	2.70e-2	0.23	3.51e-2	0.22	0.11	0.21	5.87e-2	0.22
Concrete_HighIron01	0.22	0.42	0.26	0.42	0.34	0.42	0.44	0.49	0.35	0.44
Concrete_HighIron02	0.34	0.48	0.46	0.48	0.60	0.48	0.78	0.55	0.61	0.50
Concrete_LHCb	4.20e-2	0.23	2.57e-2	0.23	3.52e-2	0.23	0.12	0.21	6.01e-2	0.22
Copper_CuAl10Fe5Ni5C	0.77	2.66	0.75	2.66	1.23	2.60	1.68	2.06	1.22	2.44
Copper_CuBe_C17200	0.68	3.20	0.72	3.20	1.28	3.14	1.78	2.45	1.26	2.93
Copper_CuBe_C17410	0.71	3.55	0.75	3.54	1.34	3.47	1.92	2.68	1.33	3.23
Copper_CuCr1Zr	0.75	3.17	0.79	3.17	1.39	3.10	1.91	2.43	1.36	2.90
Copper_CuDHP	0.74	3.20	0.78	3.20	1.39	3.13	1.92	2.44	1.37	2.93
Copper_CuETP	0.74	3.20	0.78	3.20	1.38	3.13	1.91	2.44	1.36	2.92
Copper_CuFe2P	0.73	3.13	0.78	3.13	1.37	3.07	1.88	2.40	1.34	2.87
Copper_CuNi10Fe1Mn	0.87	3.00	0.96	3.00	1.67	2.94	2.13	2.31	1.59	2.75
Copper_CuNi1P	0.75	3.17	0.80	3.17	1.41	3.11	1.93	2.43	1.38	2.90
Copper_CuNi1Si	0.76	3.15	0.80	3.15	1.42	3.09	1.94	2.41	1.38	2.88
Copper_CuNi9Sn2	0.87	3.33	0.95	3.33	1.65	3.26	2.17	2.56	1.59	3.05
Copper_CuOF	0.74	3.20	0.78	3.20	1.39	3.13	1.91	2.45	1.36	2.93
Copper_CuOFE	0.74	3.20	0.78	3.20	1.39	3.13	1.91	2.45	1.36	2.93
Copper_CuSn015	0.74	3.20	0.78	3.19	1.39	3.13	1.92	2.44	1.36	2.92
Copper_CuSP	0.74	3.19	0.78	3.18	1.38	3.12	1.91	2.44	1.35	2.91
Copper_CuZn05	0.74	3.19	0.78	3.19	1.39	3.12	1.92	2.44	1.36	2.92
Copper_GLIDCOP	0.74	3.20	0.78	3.19	1.38	3.13	1.91	2.44	1.36	2.92

Optimization during design – *ActiWiz*

Steel 316L

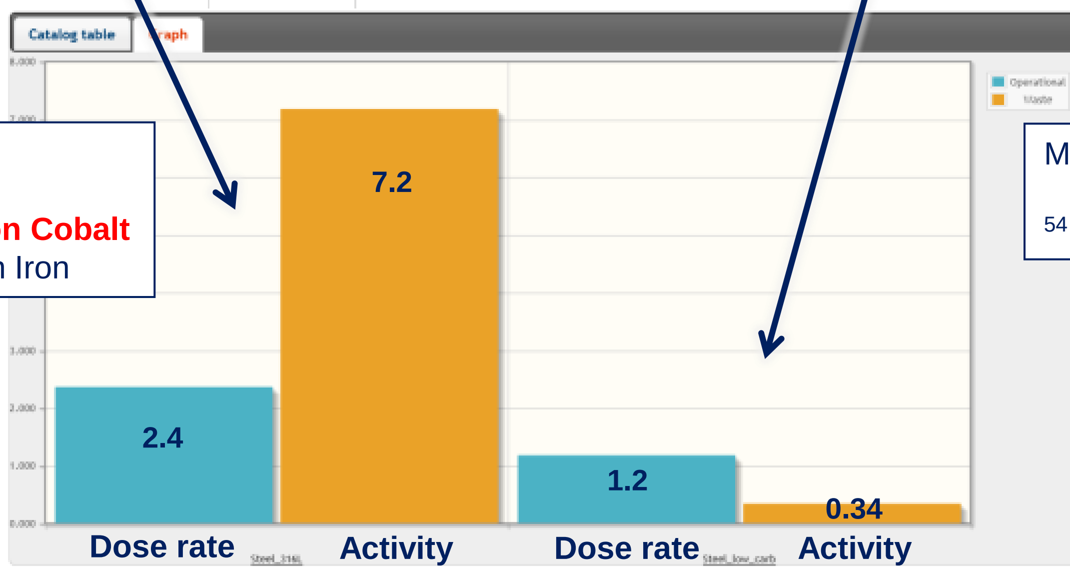
Element	Weight %
IRON	64.80
CHROMIUM	17.25
NICKEL	12.50
MOLYBDENUM	2.25
MANGANESE	2.00
SILICON	1.00
COBALT	1.00e-1
NITROGEN	5.00e-2
CARBON	3.00e-2
PHOSPHORUS	1.50e-2
SULFUR	

Cast iron

Element	Weight %
IRON	99.35
MANGANESE	0.45
CARBON	0.11
SILICON	5.00e-2
SULFUR	2.50e-2
PHOSPHORUS	2.00e-2

Main contributors:

^{60}Co (61%) produced on Cobalt
^{54}Mn (37%) produced on Iron



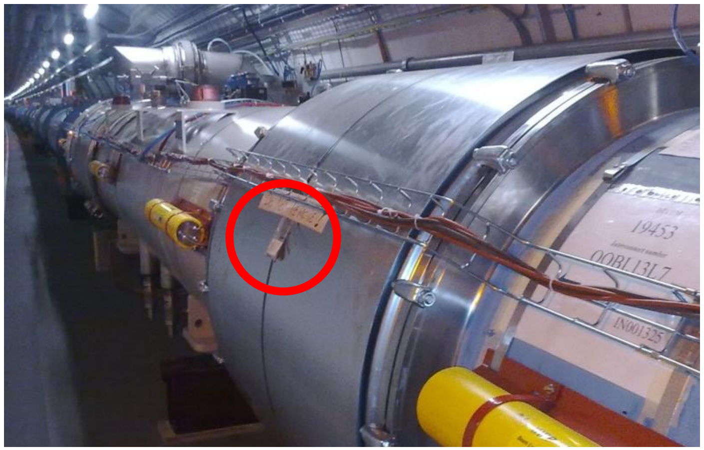
Main contributor:

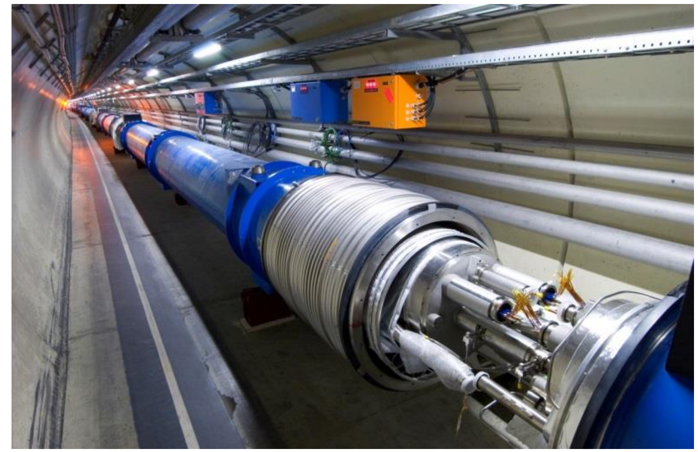
^{54}Mn produced on Iron

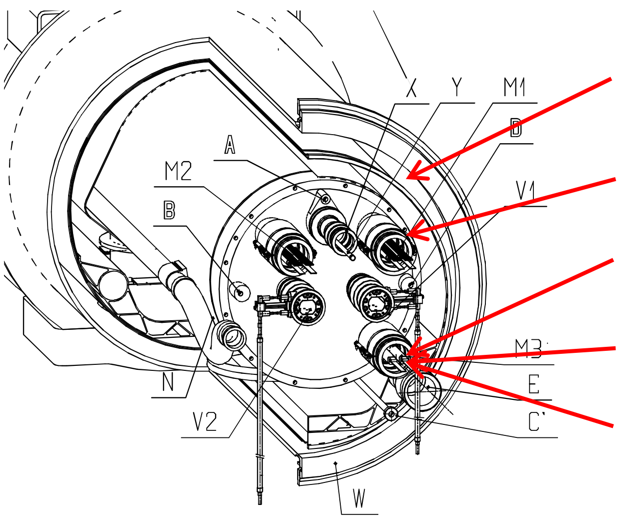
20 years irradiation
2 years cooling

Monitoring of activation – *Material samples*

Example: interconnections







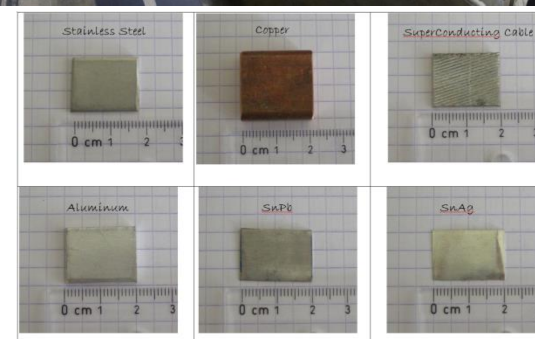
Thermal screen: aluminum

M-pipe: stainless steel

Bus bar: copper

Superconducting cable: mainly copper, niobium, titanium

Solder: tin-silver (old)
tin-lead (new)



- samples put in plastic bags and attached to the outside of interconnections
- in total 148 bags at most critical and representative positions

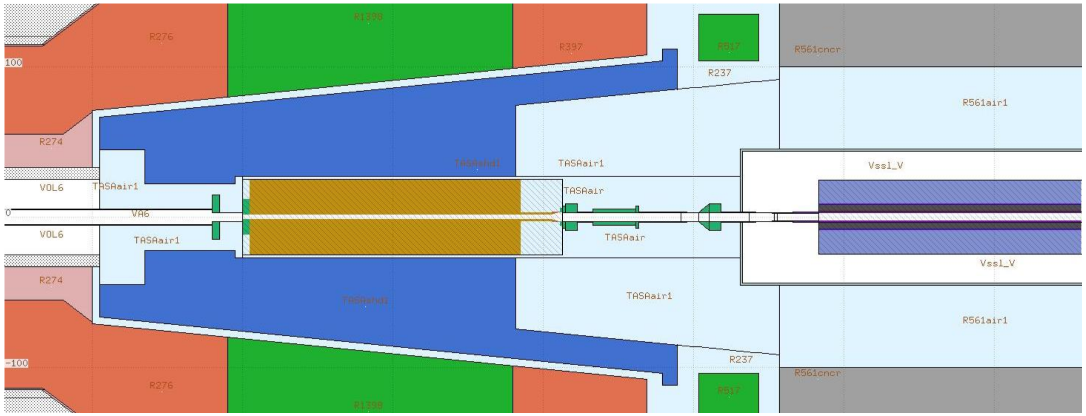
Operational scenario

	Year of LHC Operation	Peak / levelled luminosity [$cm^{-2}s^{-1}$]	Integrated luminosity [fb^{-1}]
	≤2012	0.8E+34	30
LS1			
	2015	1.45E+34	35
	2016	1.65E+34	50
	2017	1.75E+34	50
LS2			
	2019	2.0E+34	25
	2020	2.0E+34	60
	2021	2.0E+34	60
LS3			
	2024	5.0E+34	150
	2025	5.0E+34	250
	2026	5.0E+34	250
LS4			
	2028	5.0E+34	200
	2029	5.0E+34	250
	2030	5.0E+34	250
LS5			
	2032	5.0E+34	200
	2033	5.0E+34	250
	2034	5.0E+34	250
	2035	5.0E+34	250

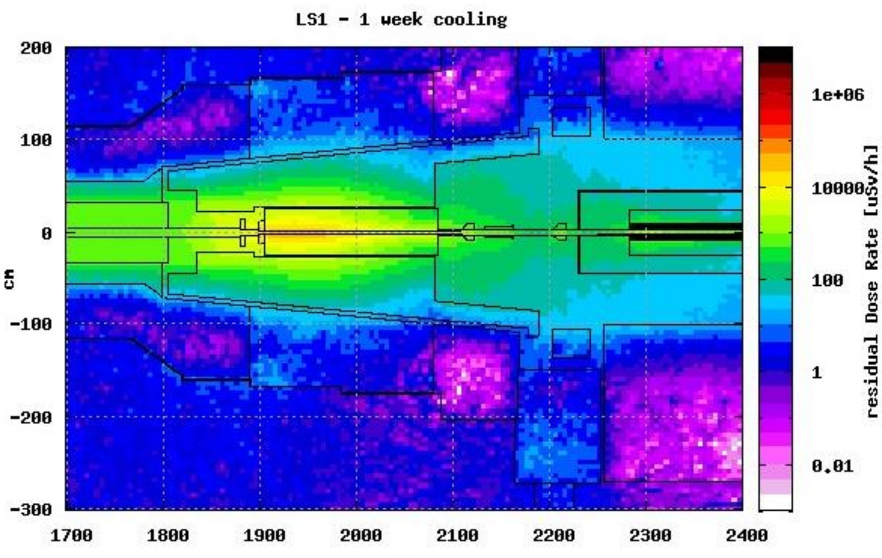
Source: S.Myers, RLIUP Workshop

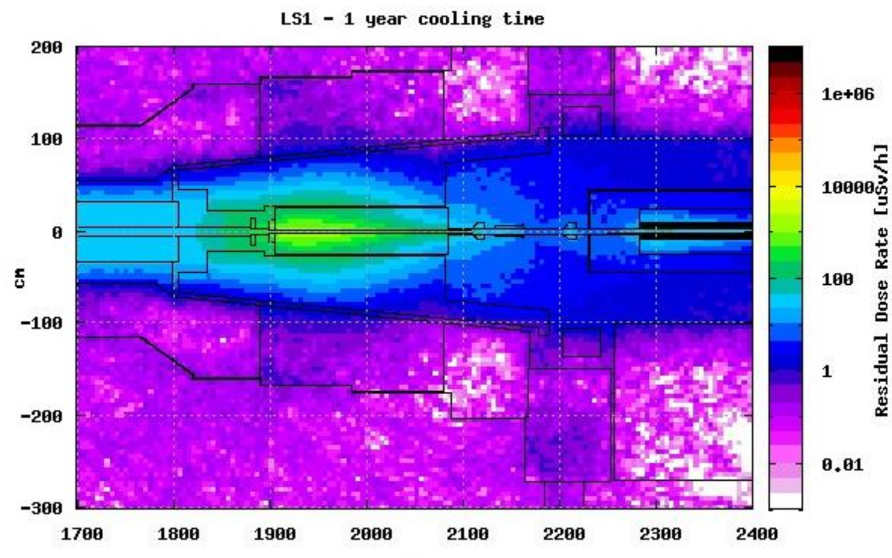
Dose rates – *LS1*

Example: TAS at Point 5



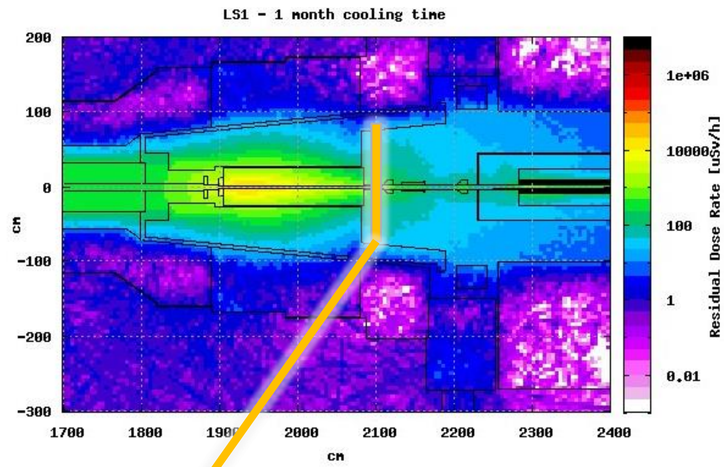
FLUKA geometry: courtesy FLUKA team

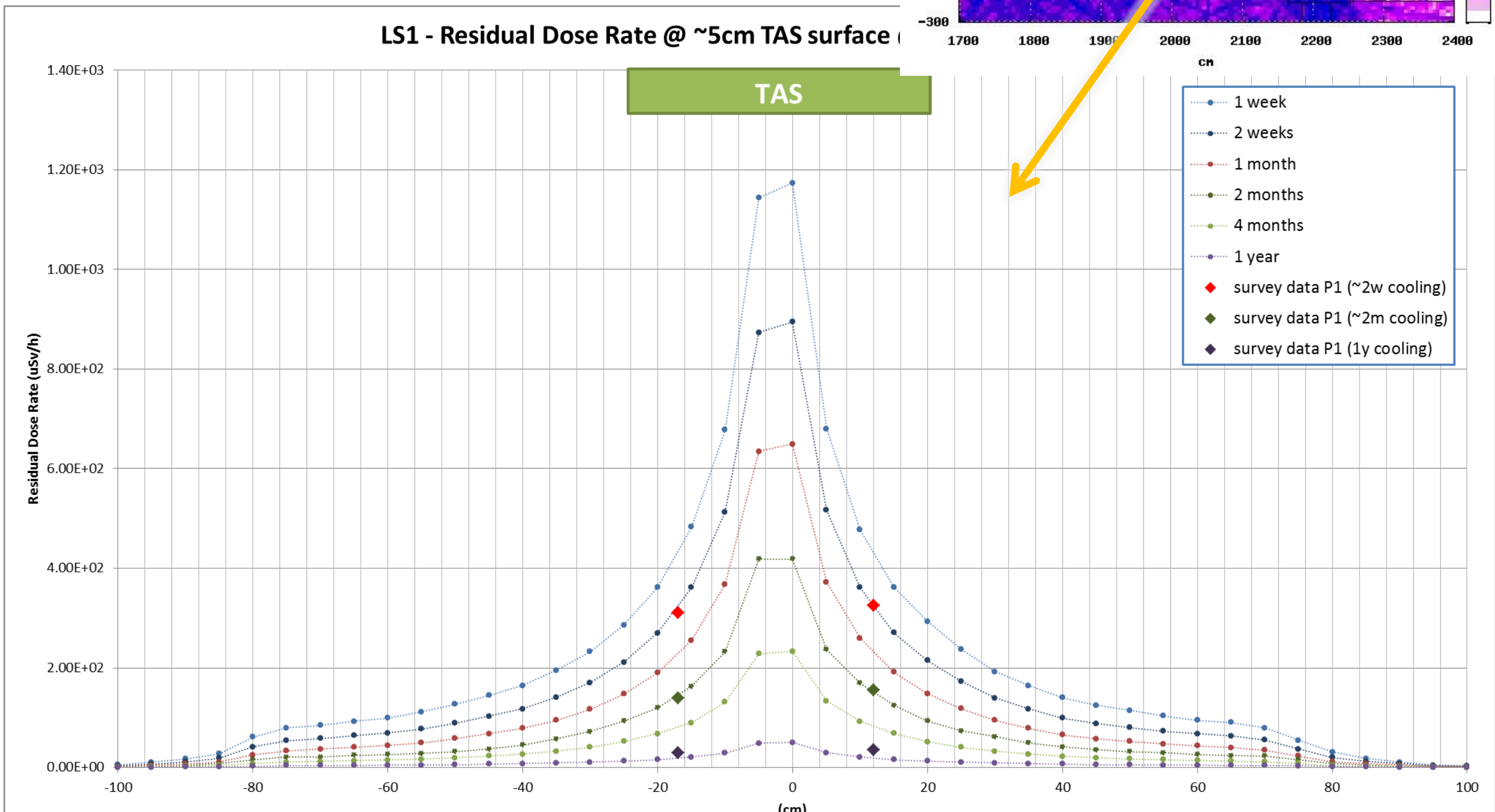




Dose rates – *LS1*

Example: TAS at Point 5

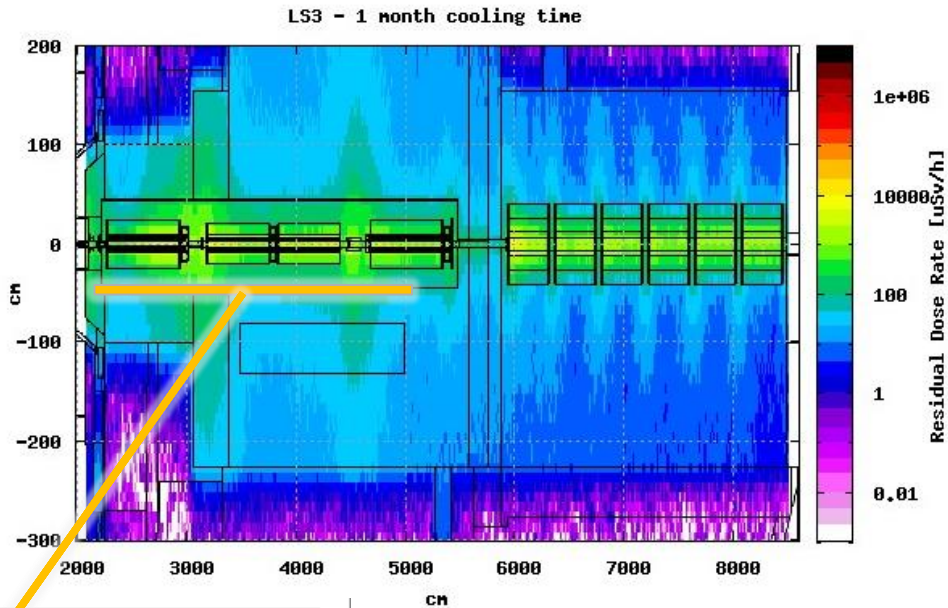


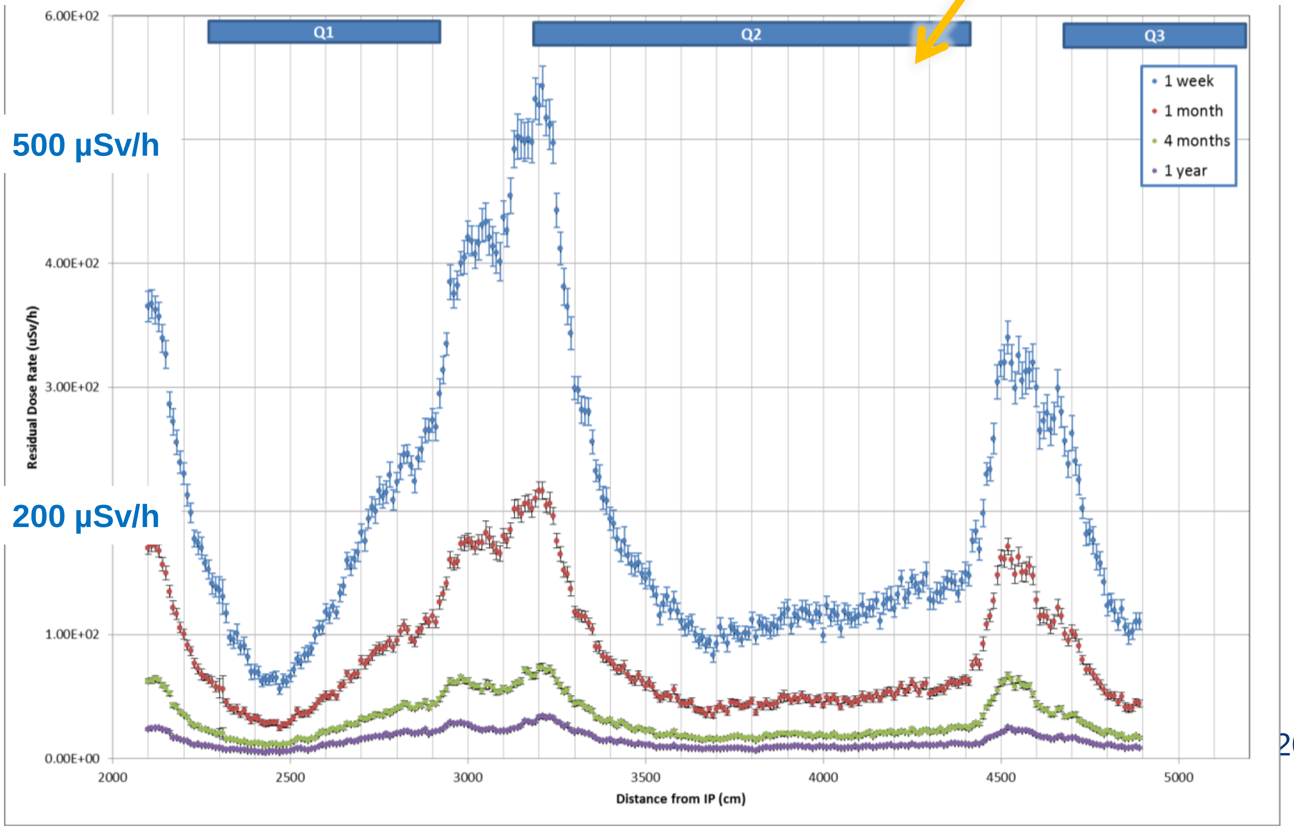


Dose rates – *LS3*

Example: Triplet at Point 5

cooling time dependence



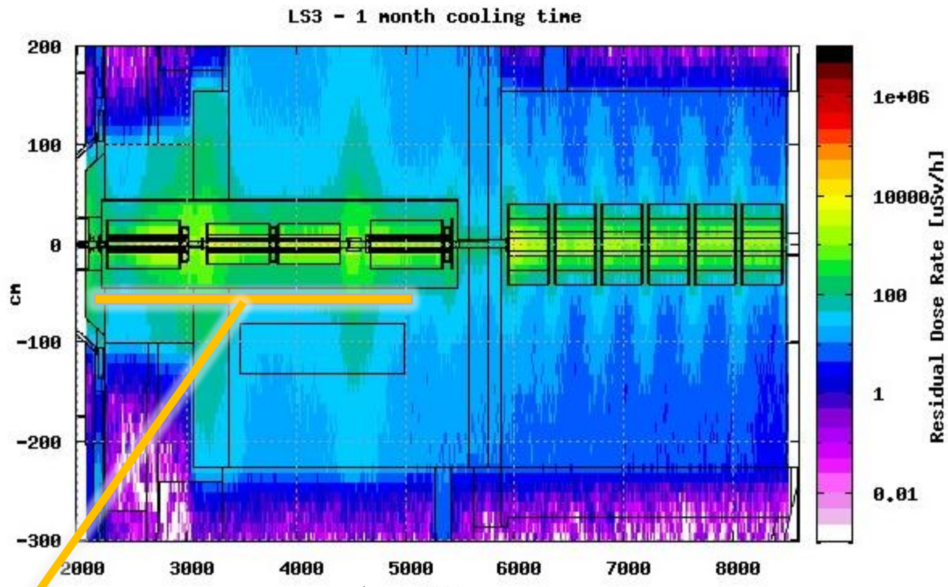


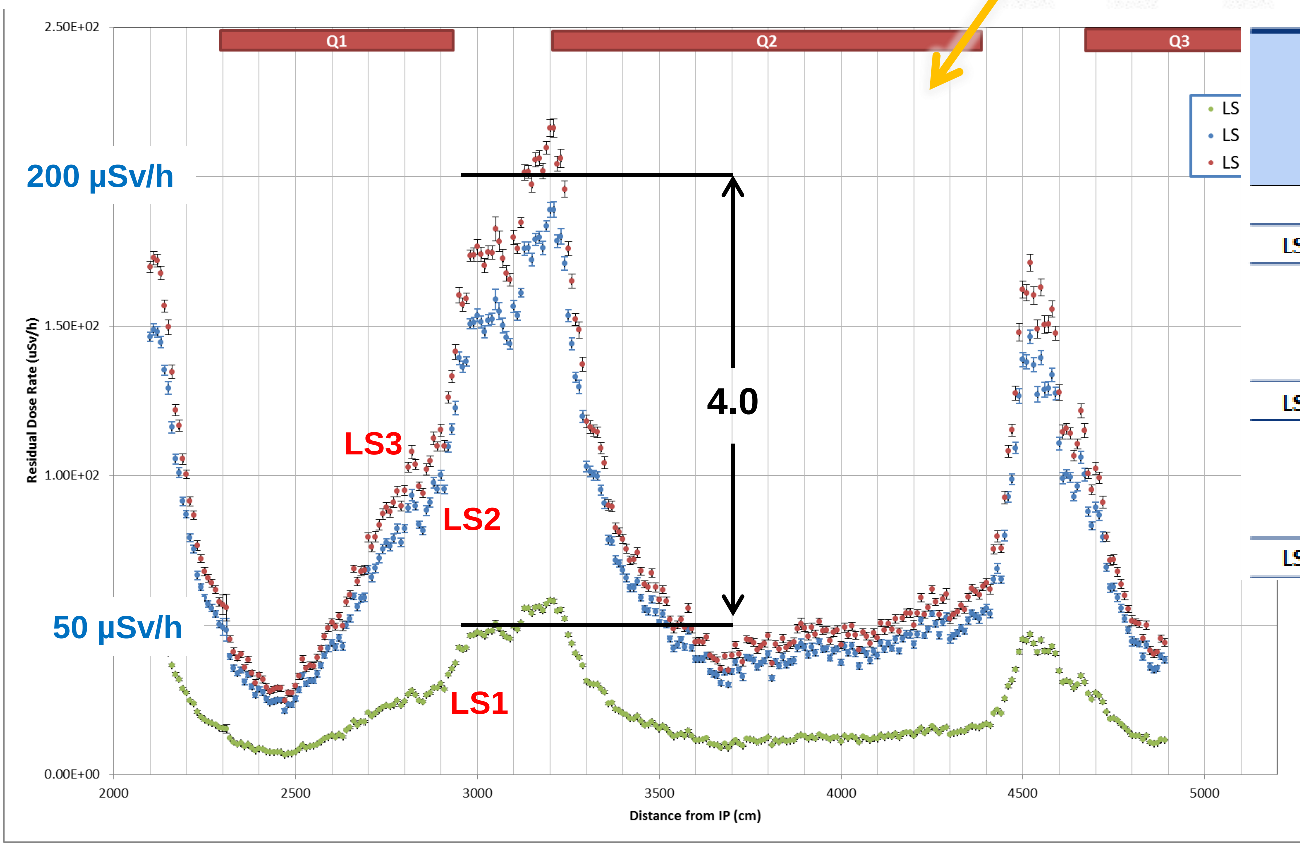
FLUKA geometry: courtesy FLUKA team

Dose rates – *Evolution*

Example: Triplet at Point 5

one month of cooling





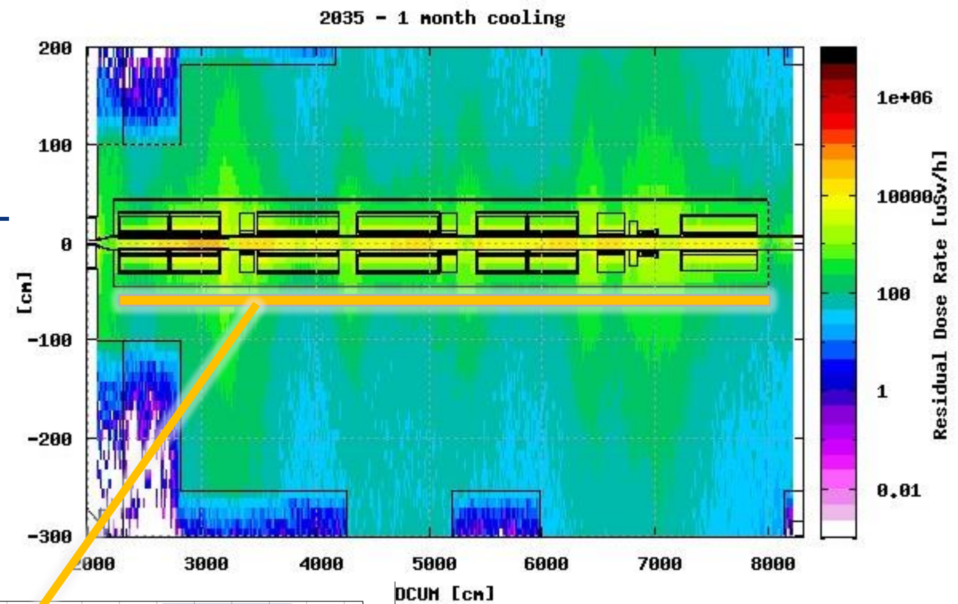
	Year of LHC Operation	Peak / levelled luminosity [$cm^{-2}s^{-1}$]	Integrated luminosity [fb^{-1}]
	≤2012	0.8E+34	30
LS1			
	2015	1.45E+34	35
	2016	1.65E+34	50
	2017	1.75E+34	50
LS2			
	2019	2.0E+34	25
	2020	2.0E+34	60
	2021	2.0E+34	60
LS3			

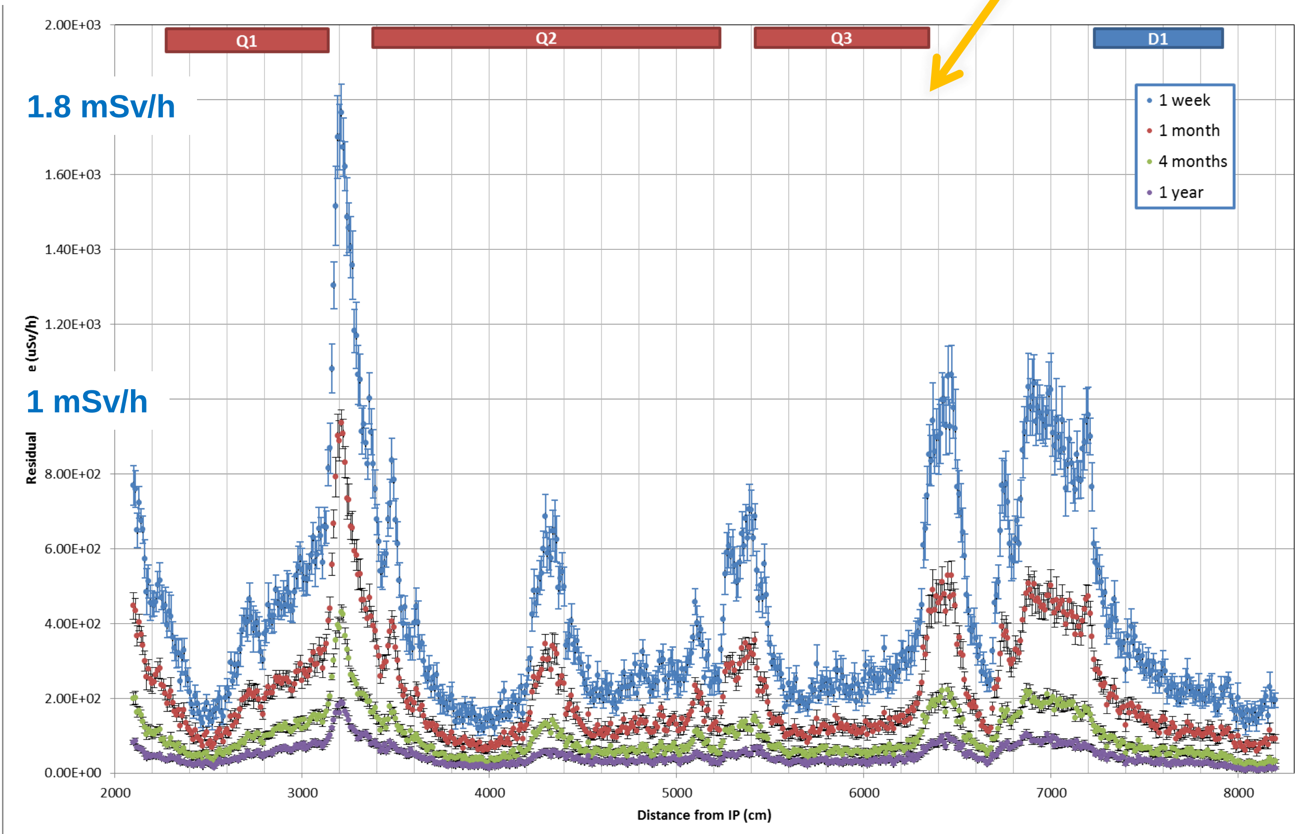
Factors LS3 / LS1
Luminosity: 2.5
Energy: 0.7

Dose rates – *2035*

Example: HL-LHC Triplet at Point 1

cooling time dependence



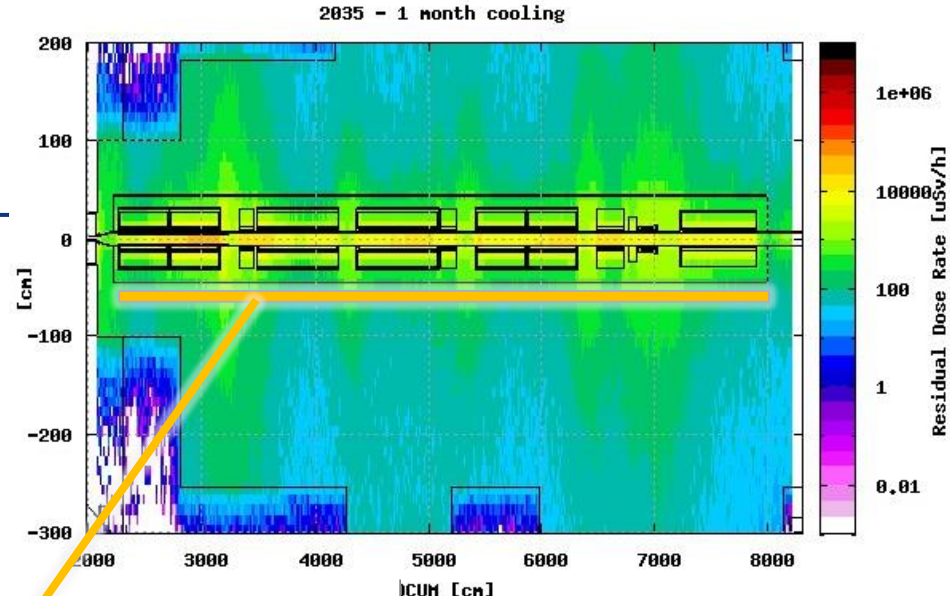


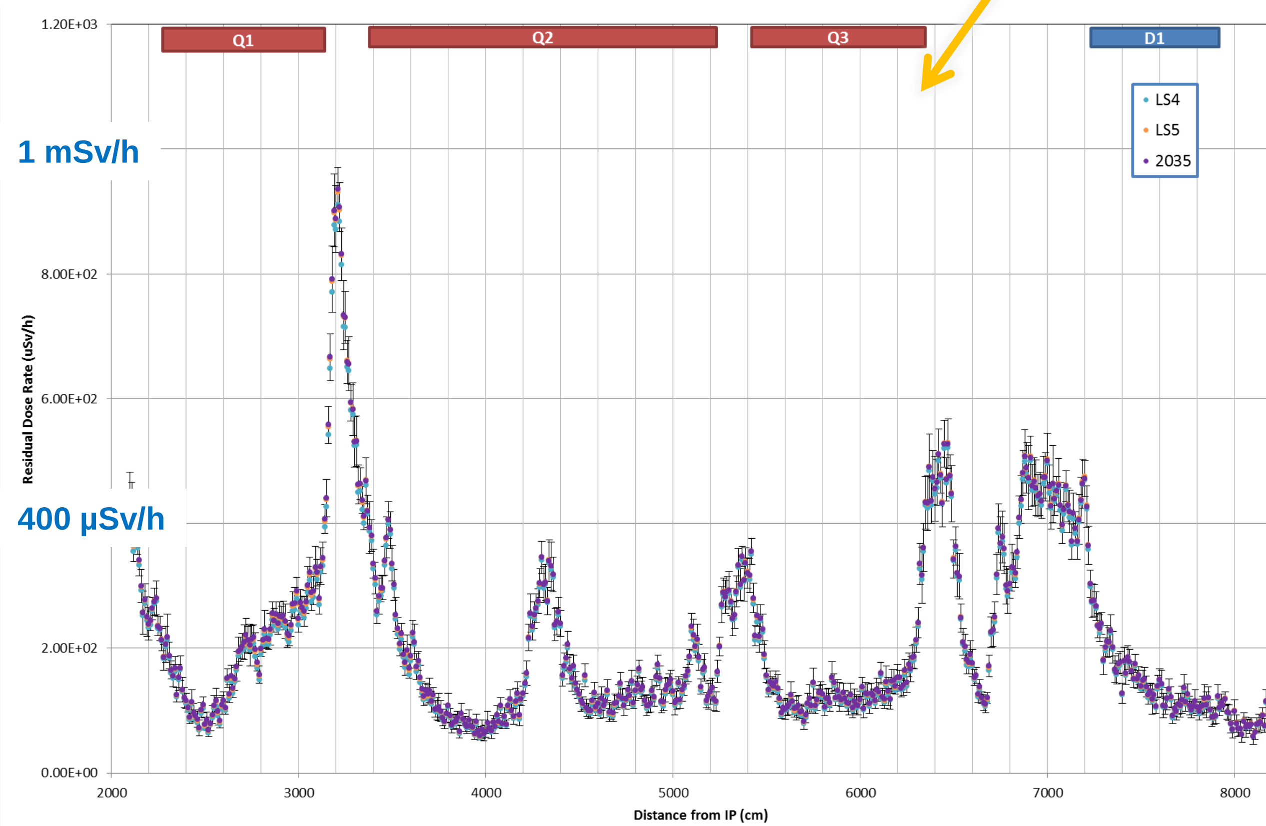
FLUKA geometry: courtesy FLUKA team

Dose rates – *2035*

Example: HL-LHC Triplet at Point 1

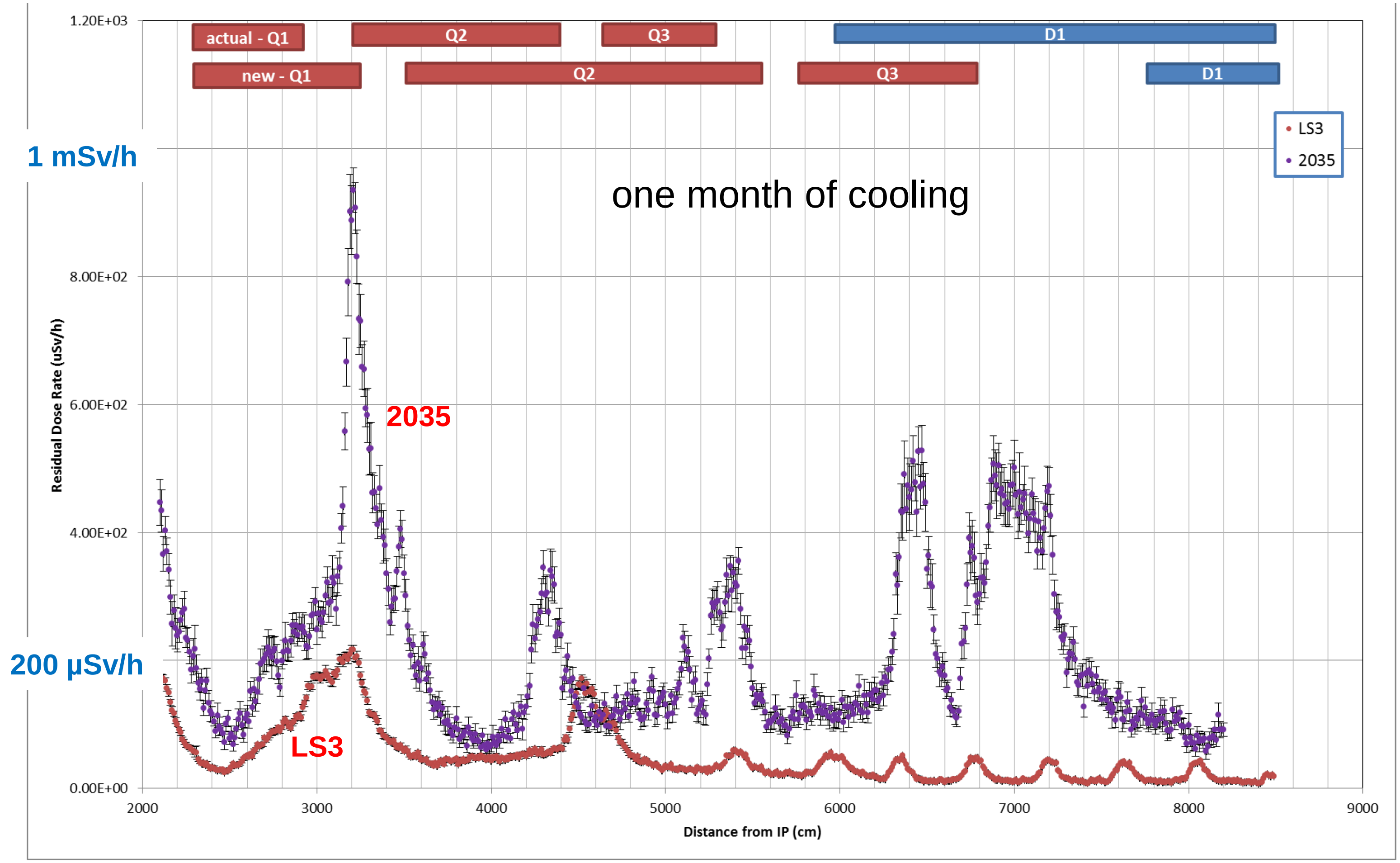
one month of cooling





	Year of LHC Operation	Peak / levelled luminosity [$cm^{-2}s^{-1}$]	Integrated luminosity [fb^{-1}]
	2024	5.0E+34	150
	2025	5.0E+34	250
	2026	5.0E+34	250
LS4			
	2028	5.0E+34	200
	2029	5.0E+34	250
	2030	5.0E+34	250
LS5			
	2032	5.0E+34	200
	2033	5.0E+34	250
	2034	5.0E+34	250
	2035	5.0E+34	250

Dose rates – *LS3 vs. 2035*



Summary

- Optimization / ALARA is a legal requirement and starts with the design of a facility. A wide range of options, tools and models is available to achieve this goal.
- Optimization of the design is applied since many years for the LHC.
- The residual dose rate increase until LS3 depends on operational scenario, cooling time and material and is about a factor of 4 for the above mentioned conditions.
- Residual doses beyond LS3 depend (in addition) strongly on the new layout of installed components. Thus, scaling factors can only be reliably given for sections of the accelerator or experiments that will not change in LS3.
- Updated residual dose rate results are available for the present LSS1/5 and are being computed for the HL-LHC upgrade (thanks to the FLUKA team for sharing inputs!).

Additional information

Optimization during operation – *ALARA procedure*

Radiation Workers

6 / 20 mSv / yr

CERN dose objective: operational periods 2 mSv / yr; long shutdowns 3 mSv / yr

ALARA categories for individual interventions

→ Detailed work-and-dose planning

→ ALARA committee

Primary criteria

Individual dose equivalent	Level I	100 µSv	Level II	1 mSv	Level III
Collective dose equivalent		500 µSv		5 mSv	

Secondary criteria

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

100 µSv / yr