Radiation Protection Aspects

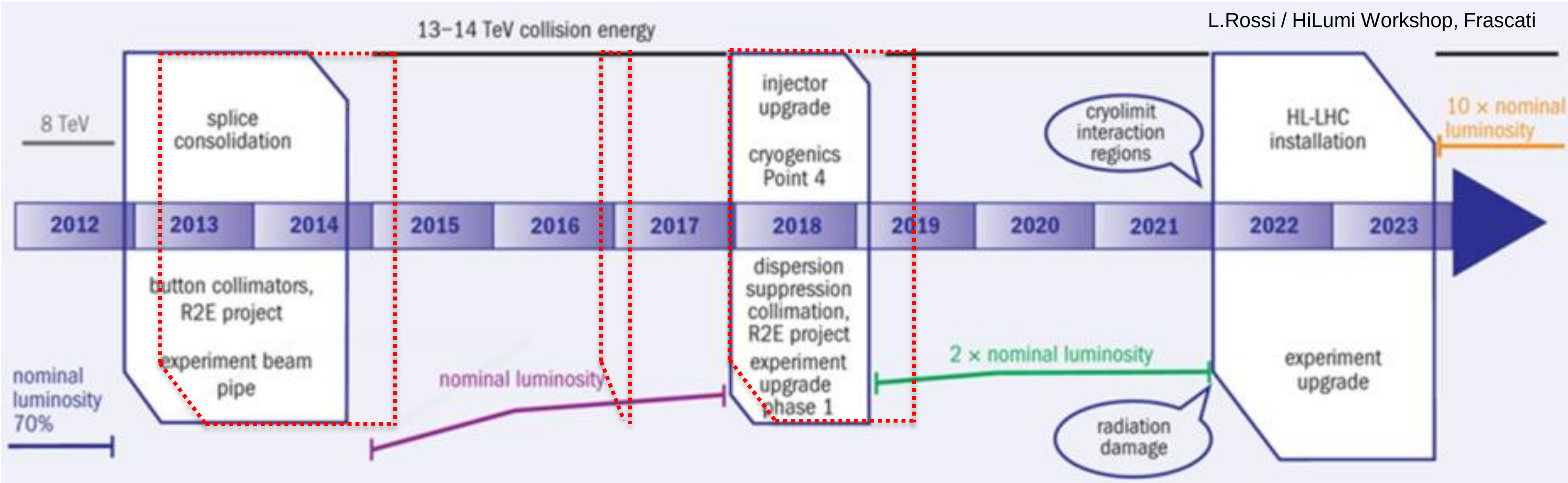
C. Adorisio, S. Roesler, C. Urscheler, Heinz Vincke
(DGS-RP)

HL-LHC WP8 – 1st Workshop Collider-Experiment Interface
CERN, November 30, 2012

Outline

1. Operational scenario(s) until Long Shutdown 3
2. Residual dose rate predictions for ATLAS and CMS and for the different Long Shutdowns
3. Dose rate scaling factors between Long Shutdowns and for different cooling times
4. Residual dose rate estimates for LSS1 and LSS5 and consequences for work procedures
5. Radiological optimization of the HiLumi LHC design

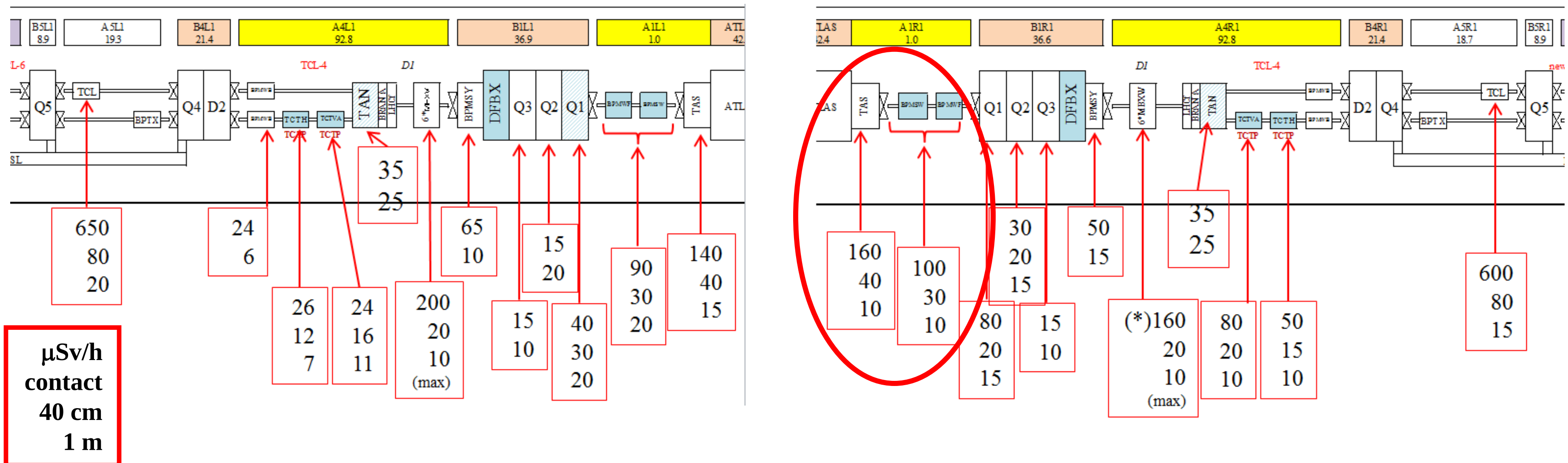
Operational scenario(s)



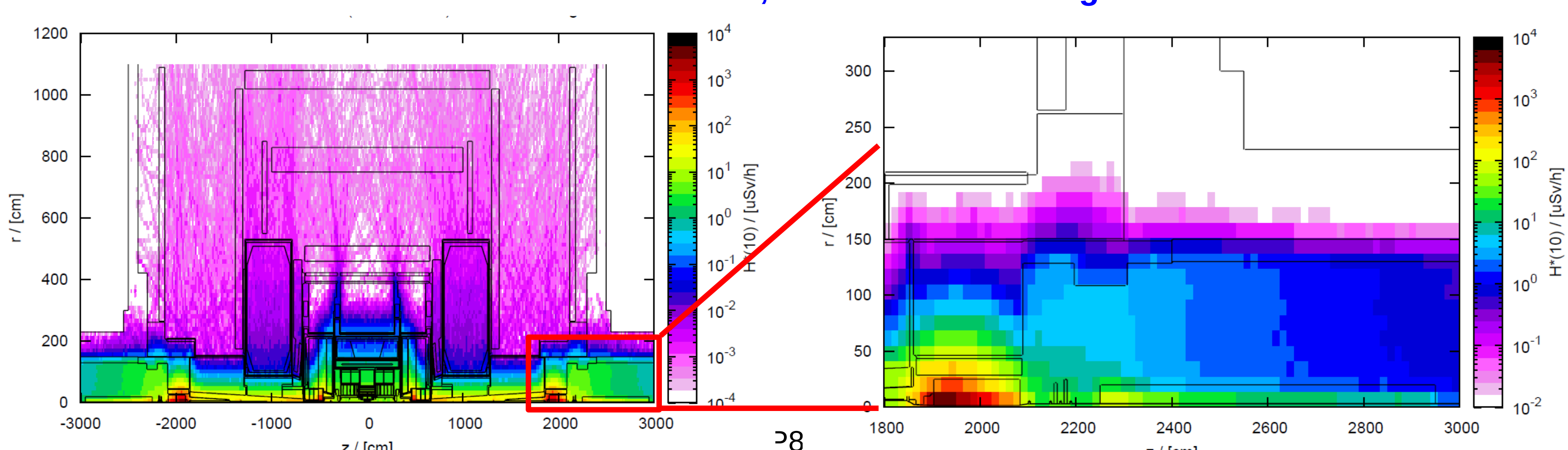
		2015	2016	2017	LS2	2019	2020	2021	LS3
ATLAS	L_{int} (fb^{-1})	52	41	41		83	83	83	
	L_{peak} ($cm^{-2}s^{-1}$)	1.0×10^{34}	1.0×10^{34}	1.0×10^{34}		2.0×10^{34}	2.0×10^{34}	2.0×10^{34}	
CMS	L_{int} (fb^{-1})	50	80	100		150	150	150	
	L_{peak} ($cm^{-2}s^{-1}$)	1.2×10^{34}	2.3×10^{34}	2.5×10^{34}		3.5×10^{34}	3.5×10^{34}	3.5×10^{34}	

Residual dose rates LS1 – *ATLAS*

Predictions for March 2013 based on TS3 survey measurements

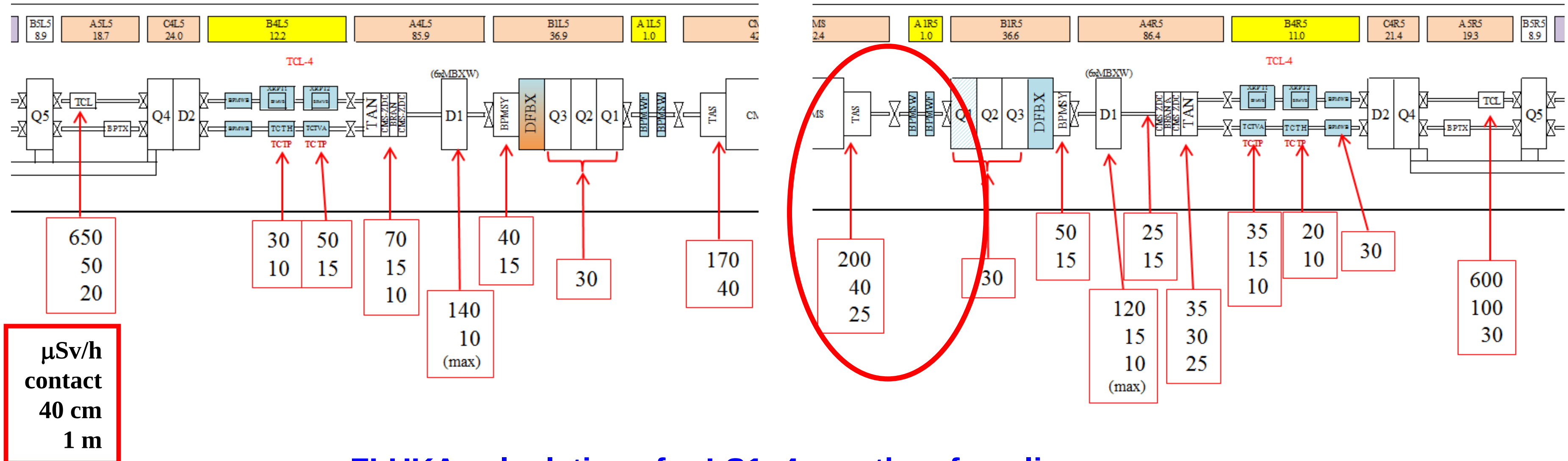


FLUKA calculations for LS1, 4 months of cooling

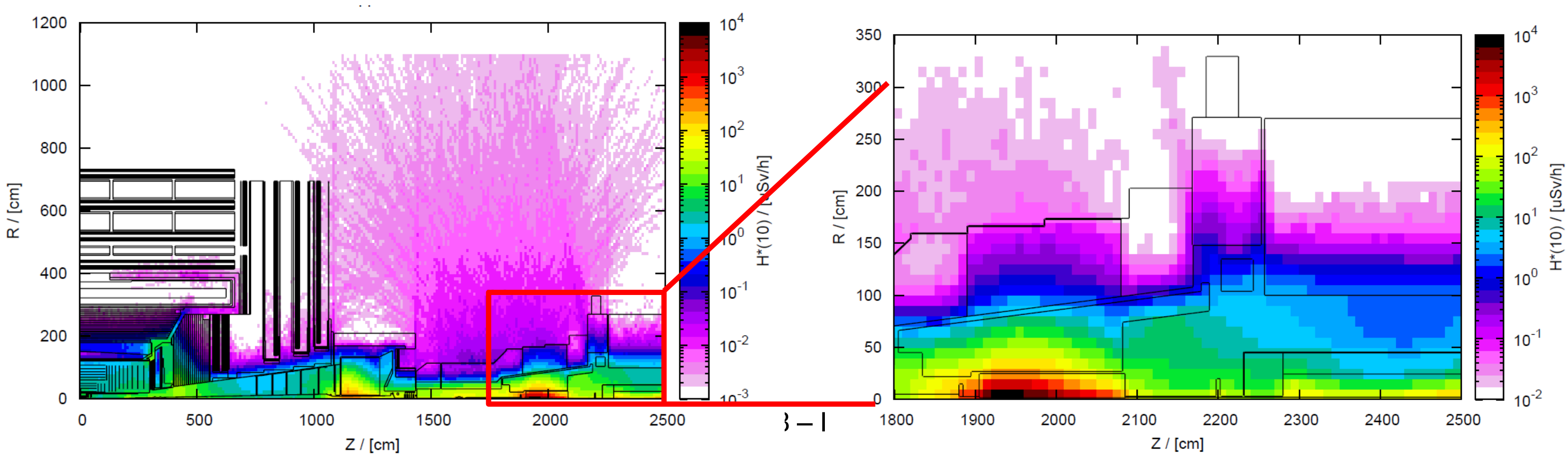


Residual dose rates LS1 – *CMS*

Predictions for March 2013 based on TS3 survey measurements



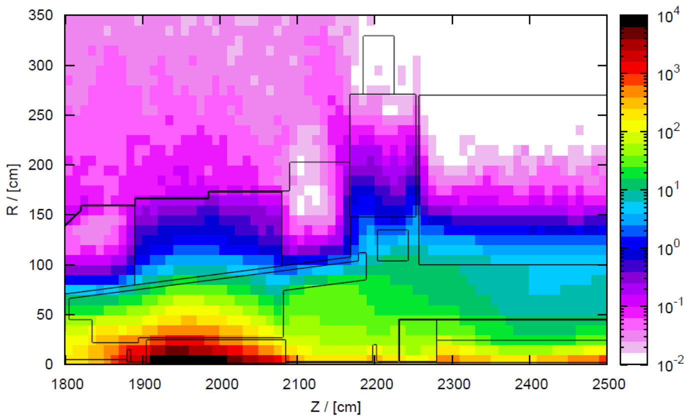
FLUKA calculations for LS1, 4 months of cooling



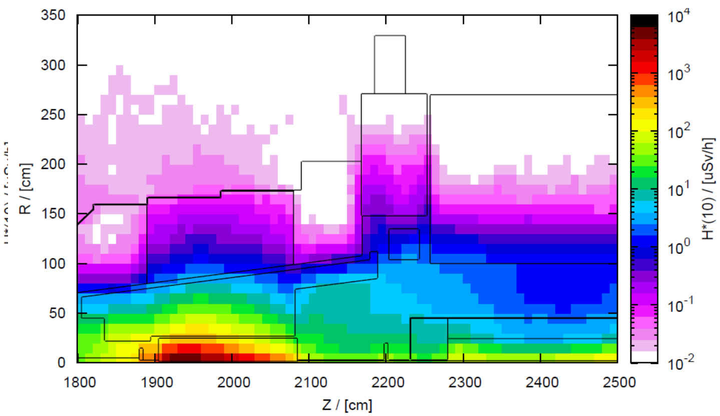
Residual dose rates LS1 – *CMS*

FLUKA calculations for LS1, cooling time dependence

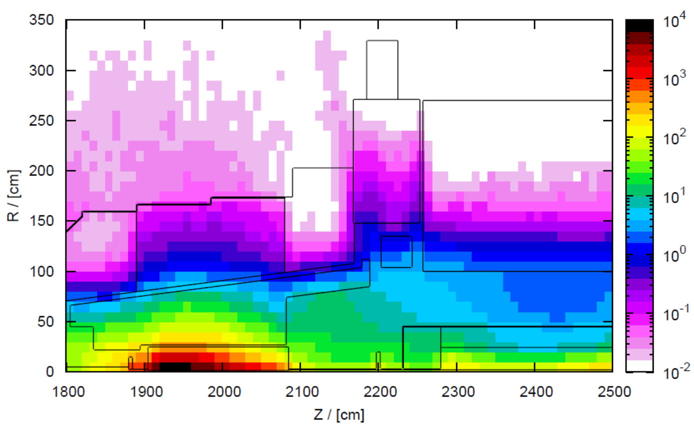
one month



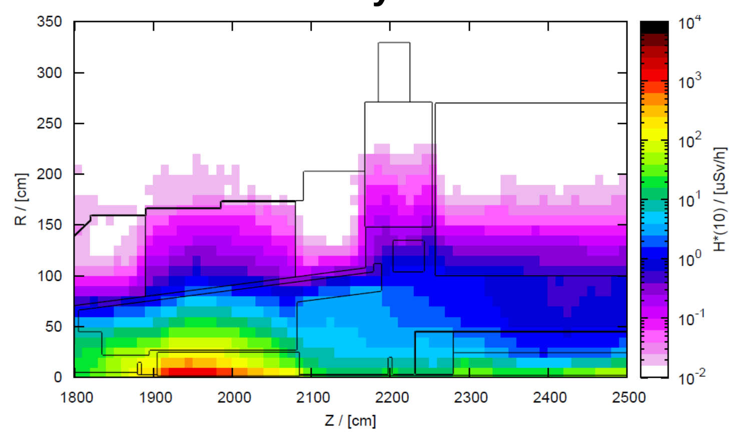
6 months



4 months

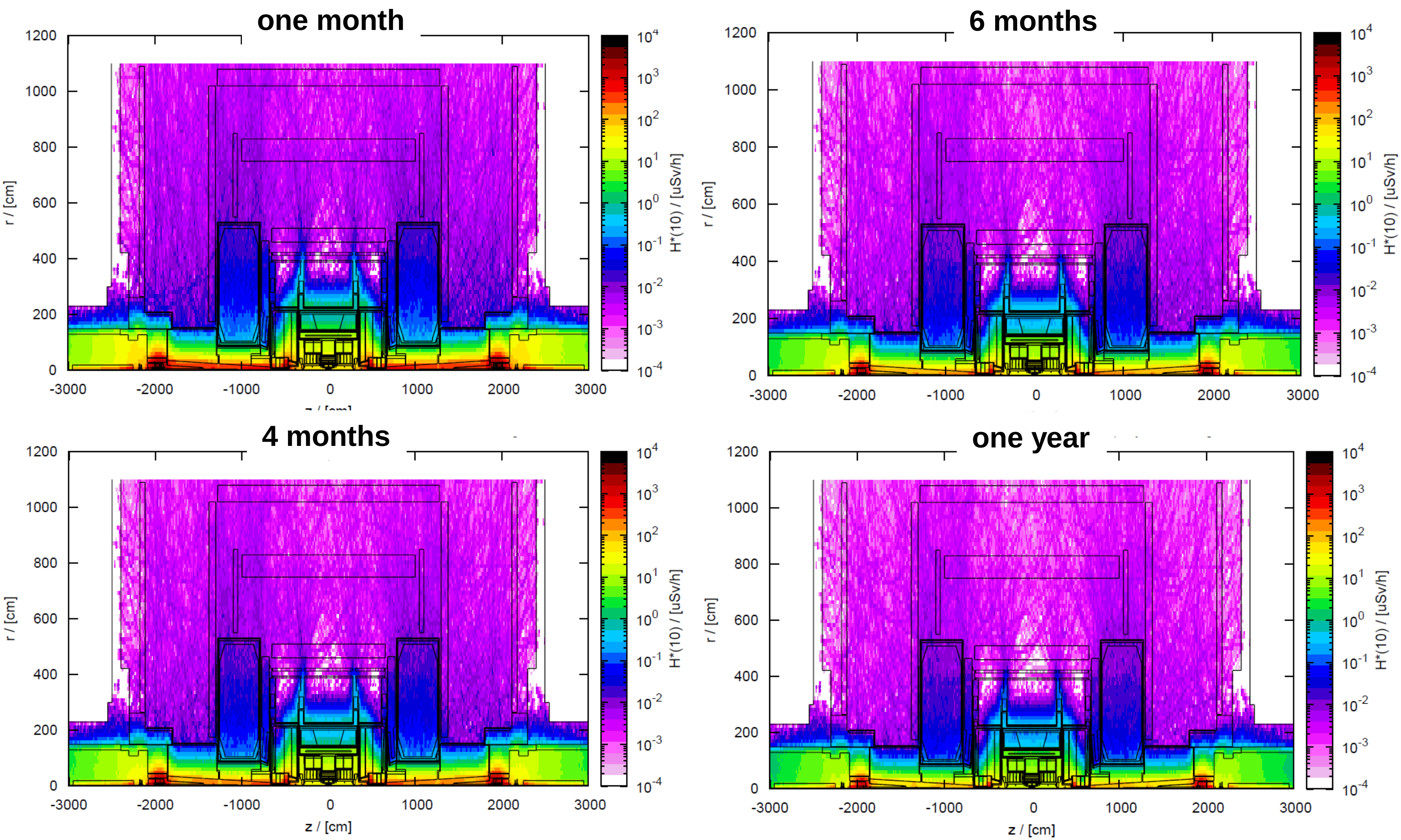


one year

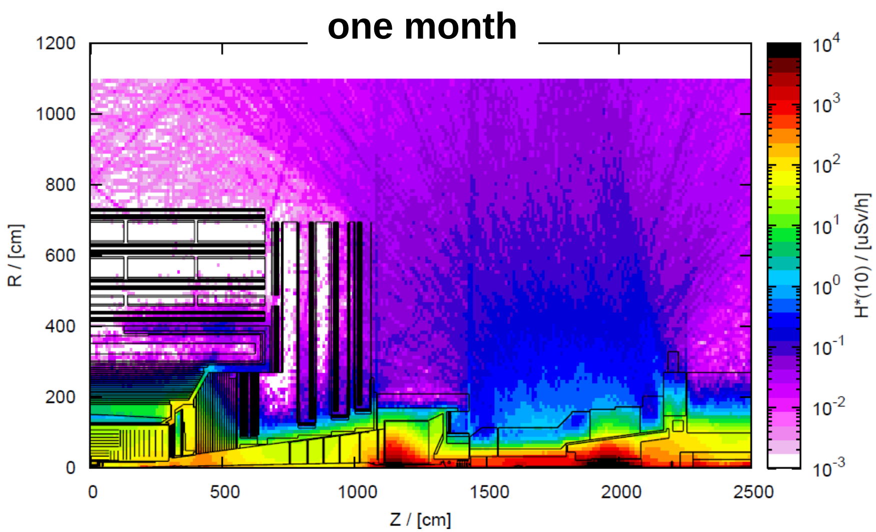


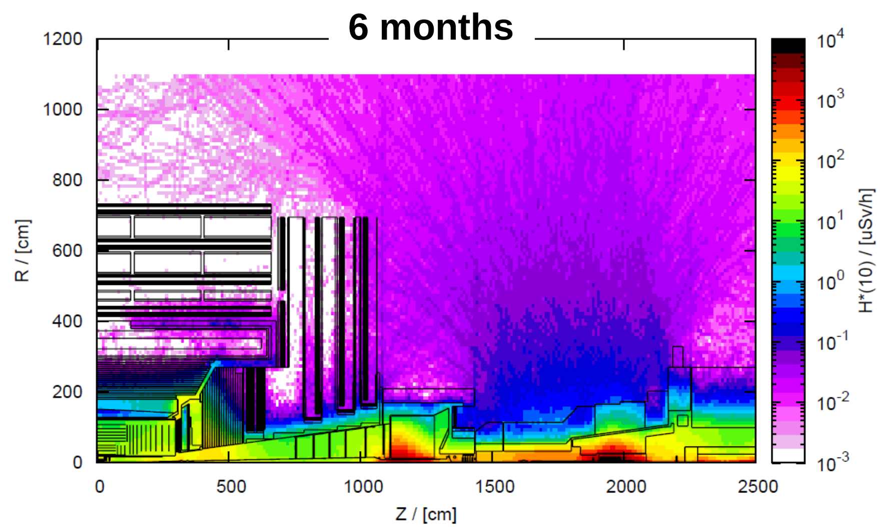
t_{cool}	Scaling factor
One month	1.0
4 months	0.35
6 months	0.23
One year	0.12

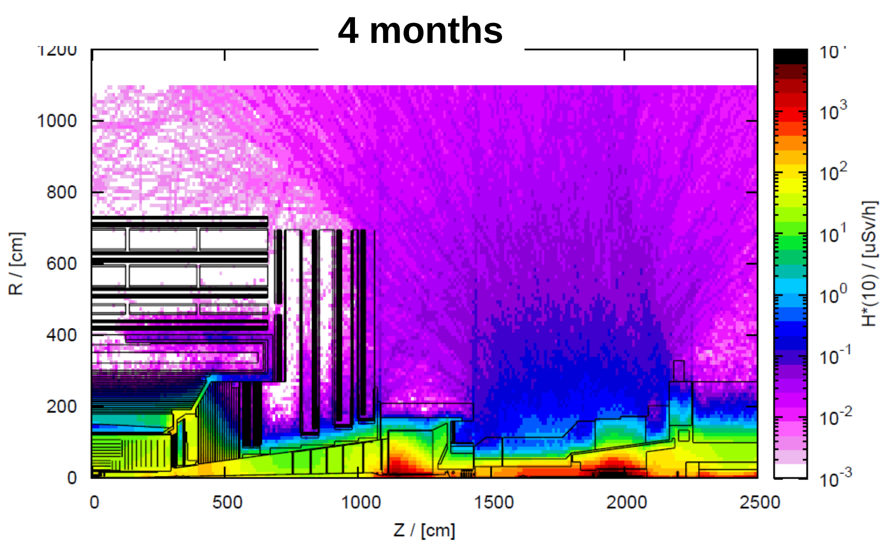
Residual dose rates LS2 – *ATLAS*

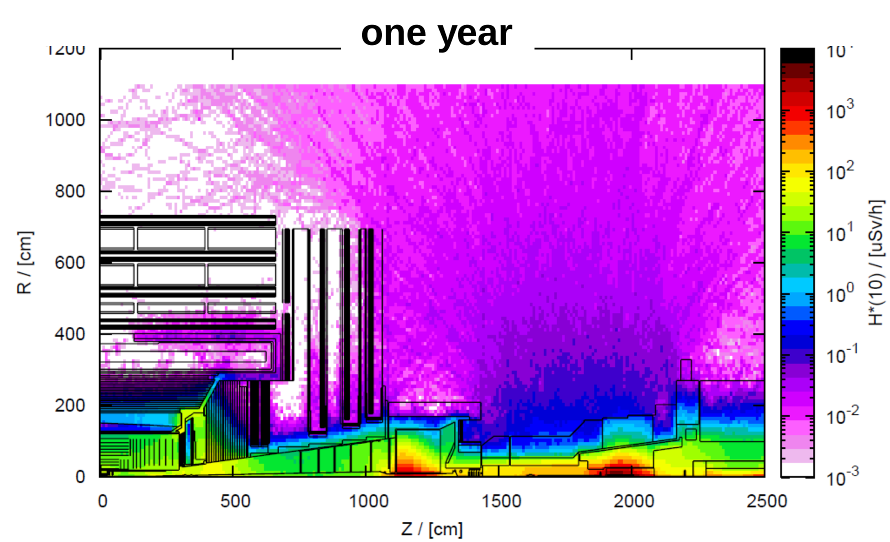


Residual dose rates LS2 – *CMS*



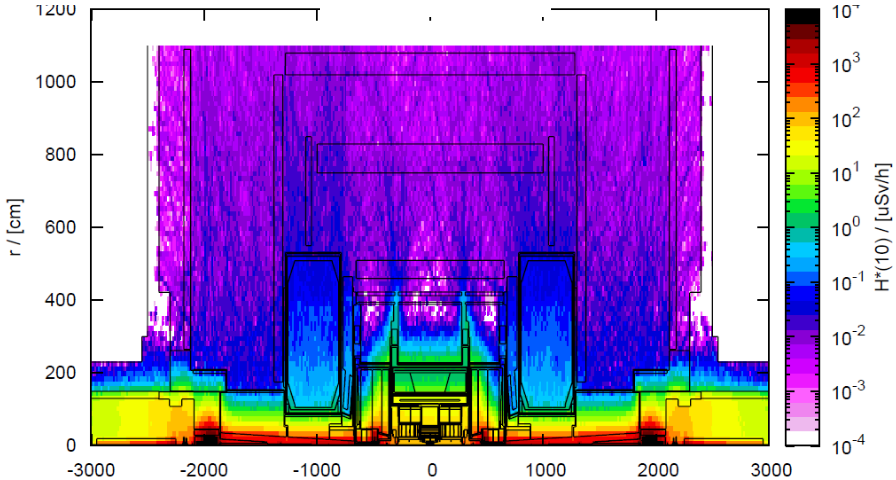




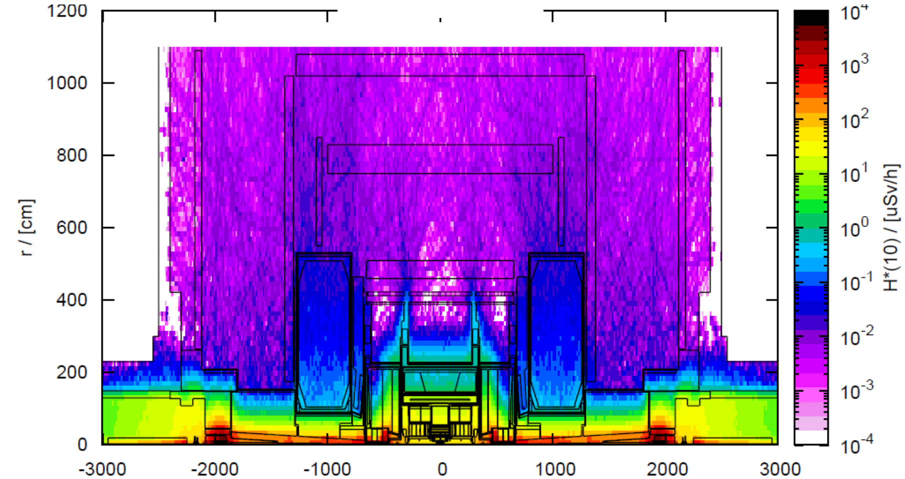


Residual dose rates LS3 – *ATLAS*

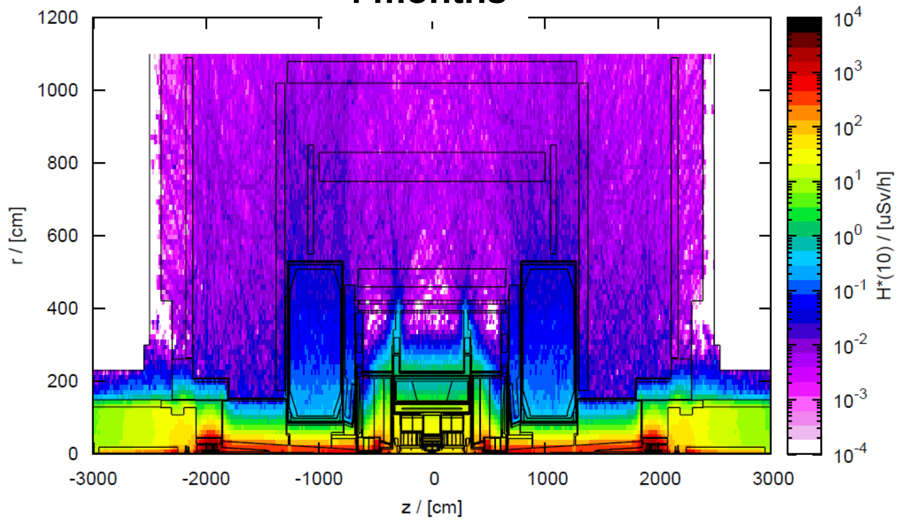
one month



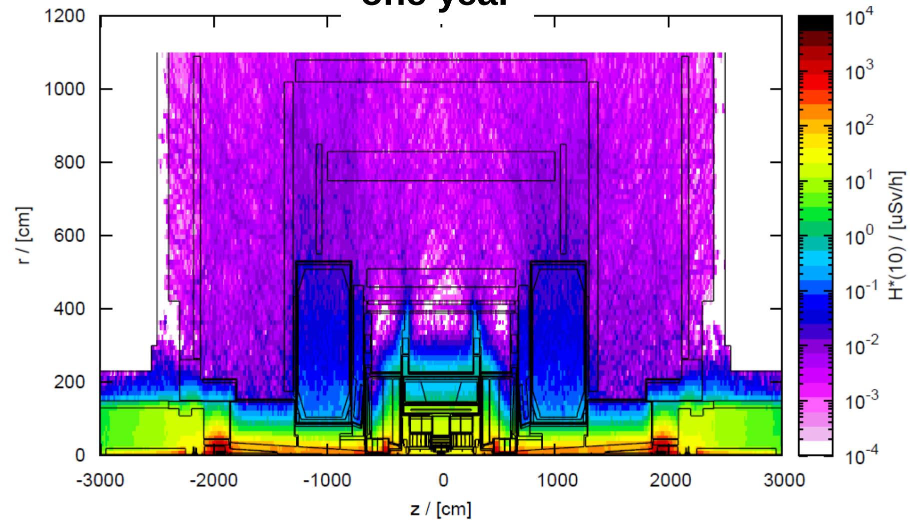
6 months



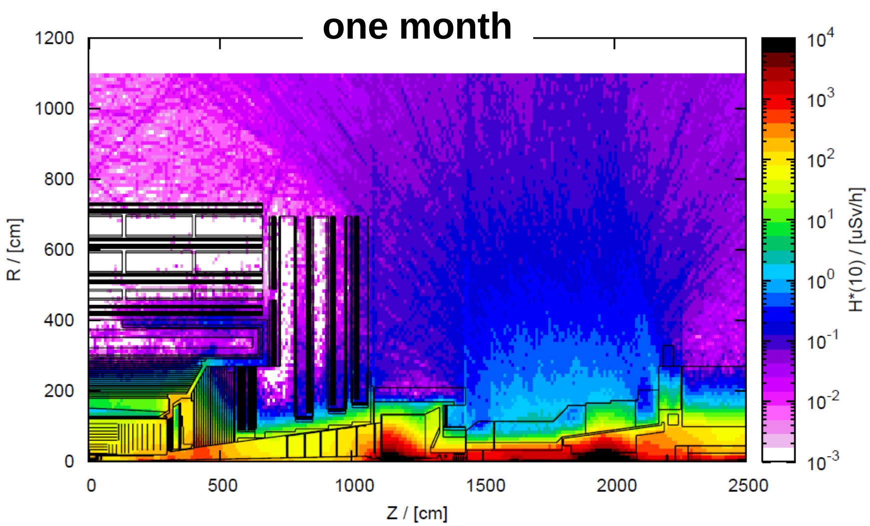
4 months

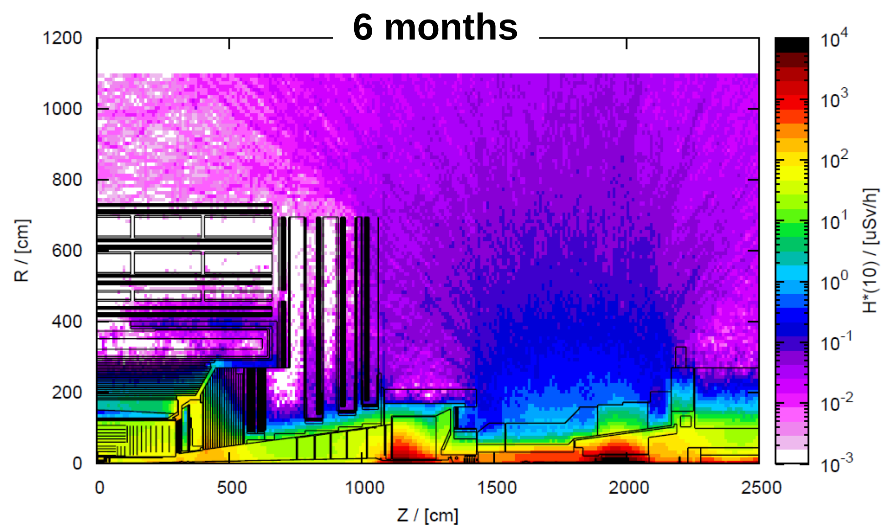


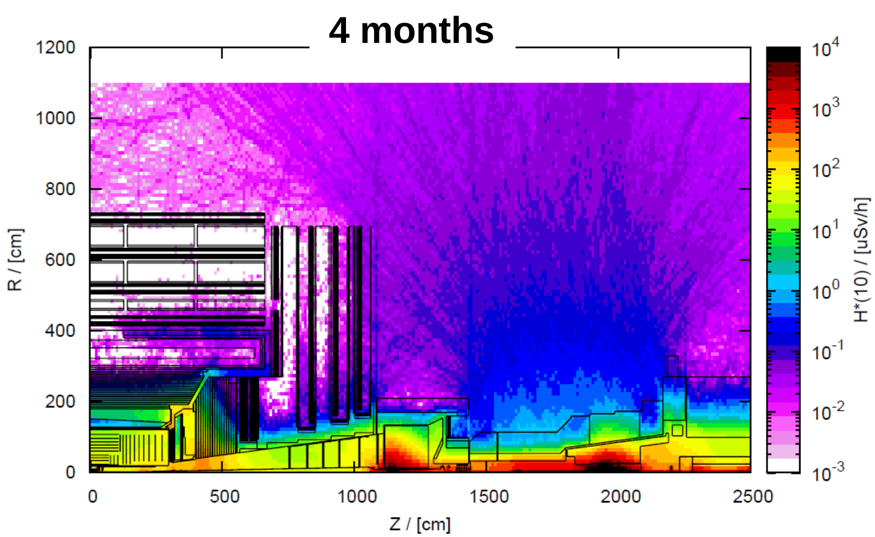
one year

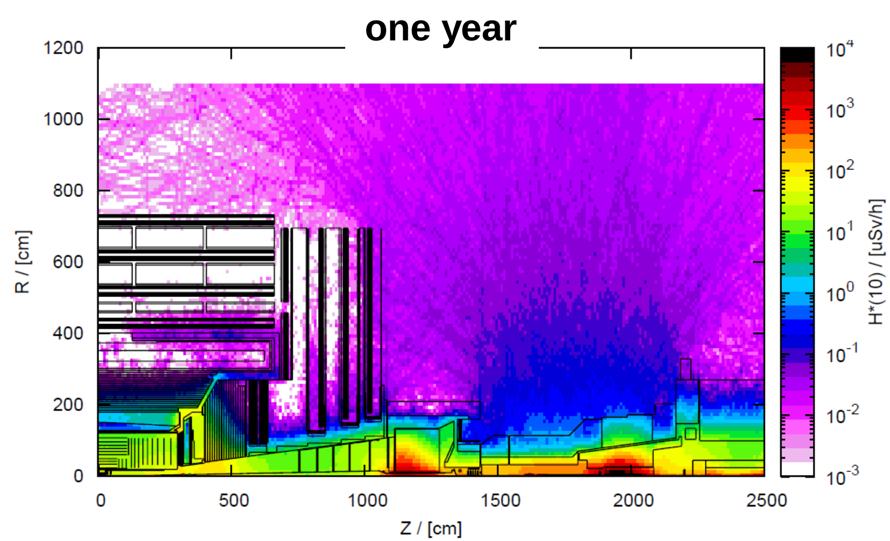


Residual dose rates LS3 – *CMS*









Scaling factors

		2015	2016	2017	LS2	2019	2020	2021	LS3
ATLAS	L_{int} (fb^{-1})	52	41	41		83	83	83	
	L_{peak} ($cm^{-2}s^{-1}$)	1.0×10^{34}	1.0×10^{34}	1.0×10^{34}		2.0×10^{34}	2.0×10^{34}	2.0×10^{34}	
CMS	L_{int} (fb^{-1})	50	80	100		150	150	150	
	L_{peak} ($cm^{-2}s^{-1}$)	1.2×10^{34}	2.3×10^{34}	2.5×10^{34}		3.5×10^{34}	3.5×10^{34}	3.5×10^{34}	

Evolution of residual dose rates from LS1 until LS3

t_{cool} = 4 months	ATLAS	CMS
LS2 / LS1	4.1	9.0
LS3 / LS1	8.5	16.0
LS3 / LS2	2.0	1.7

Cooling time dependence of residual dose rates

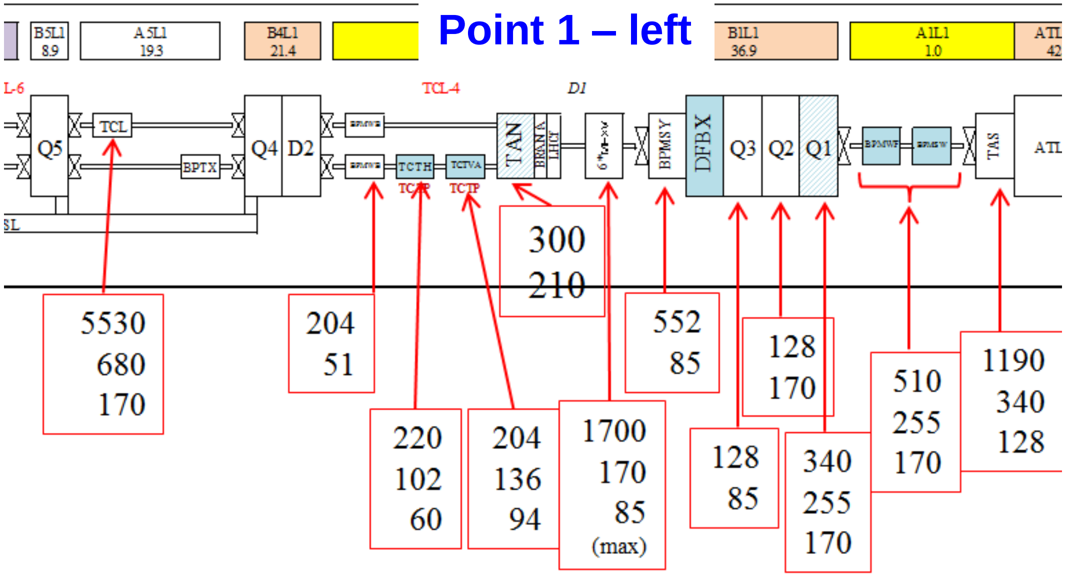
t_{cool}	LS1	LS3
One month	1.0	1.0
4 months	0.35	0.47
6 months	0.23	0.35
One year	0.12	0.2

Residual dose rates LS3 – *LSS1/5*

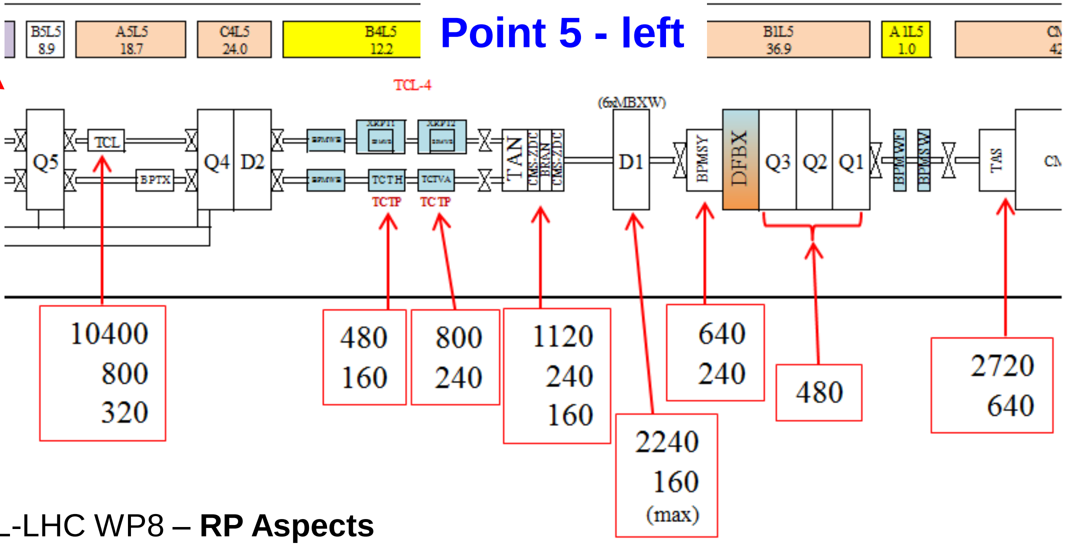
4 month cooling

t_{cool} = 4 months	ATLAS	CMS
LS2 / LS1	4.1	9.0
LS3 / LS1	8.5	16.0
LS3 / LS2	2.0	1.7

Point 1 – left

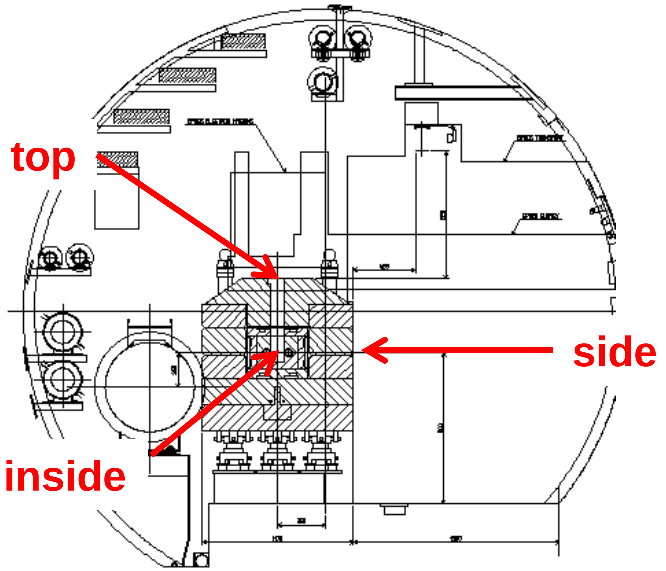


Point 5 - left



µSv/h
contact
40 cm
1 m

Residual dose rates LS3 – *TAN at Point 1*



4 month cooling

µSv/h	LS1	LS2	LS3
top	35	140	300
side	18	74	150
inside	2600	10700	22100

Radiological classification

	Area classification	Dose limit	Ambient dose equivalent rate		Specific airborne radioactivity	Specific surface contamination	Access, Personnel categories	Monitoring, Personal dosimetry
			At permant workplaces	In low-occupancy areas				
	Non-designated Area	1 mSv / y	$< 0.5\ \mu Sv\ h^{-1}$	$< 2.5\ \mu Sv\ h^{-1}$	0.05 CA	-	no restriction, all	passive or active, not required
	Supervised Radiation Area	6 mSv / y	$< 3\ \mu Sv\ h^{-1}$	$< 15\ \mu Sv\ h^{-1}$	< 0.1 CA		supervised, radiation workers and VCT	passive or active, personal dosimeter
Controlled Radiation Area	Simple Controlled Radiation Area		$< 10\ \mu Sv\ h^{-1}$	$< 50\ \mu Sv\ h^{-1}$	< 0.1 CA			active, personal dosimeter
	Limited Stay Area	20 mSv / y		$< 2\ mSv\ h^{-1}$	<100 CA	< 4000 CS	controlled, radiation workers	active, personal dosimeter and operational dosimeter
	High Radiation Area			$<100\ mSv\ h^{-1}$	< 1000 CA	< 40000 CS		
	Prohibited Area			$> 100\ mSv\ h^{-1}$	> 1000 CA	> 40000 CS		

EDMS No. 810149

→ LSS1 and LSS5 will be Limited Stay Areas during LS2 and LS3 with local spots classified as High Radiation Area

Optimization – *Safety Code F*

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.

Optimization starts with the design!

Optimization – *ALARA procedure*

Optimization is legal requirement if accumulated dose exceeds 100 µSv (ALARA)

Optimization includes:
- work coordination
- work procedures
- handling tools
- design
- material

Group 1 criteria: determine ALARA Level classification
Group 2 criteria: can be used by RP/RSO to increase classification

Formal work-and-dose-planning (DIMR) as from ALARA Level 2

ALARA committee if ALARA Level 3

Dose interval (mSv)	Persons Concerned	Persons Concerned	Persons Concerned	Persons Concerned	Persons Concerned	Persons Concerned	Persons Concerned
	2005	2006	2007	2008	2009	2010	2011
0.0	3074	4192	5131	5143	5042	5418	5315
0.1-0.9	1522	1738	898	1020	1219	1514	1984
1.0-1.9	53	37	33	40	39	31	31
2.0-2.9	9	17	2	3	13	6	7
3.0-3.9	3	4	1	1	2	-	-
4.0-4.9	4	2	1	1	-	-	-
5.0-5.9	1	-	-	-	-	-	-
> 6.0	-	-	-	-	-	-	-

Group 1 criteria

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 :

100 µSv | 1 mSv

niveau I | niveau II | 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 :

500 µSv | 5 mSv

niveau I | niveau II | niveau III

Group 2 criteria

CRITÈRE DE DÉBIT DE DOSE

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

50 µSv·h^{-1} | 2 mSv·h^{-1}

niveau I | niveau II | niveau III

CRITÈRE DE CONTAMINATION ATMOSPHÉRIQUE

Activité aérienne spécifique CA :

5 CA | 200 CA

niveau I | niveau II | niveau III

CRITÈRE DE CONTAMINATION SURFACIQUE

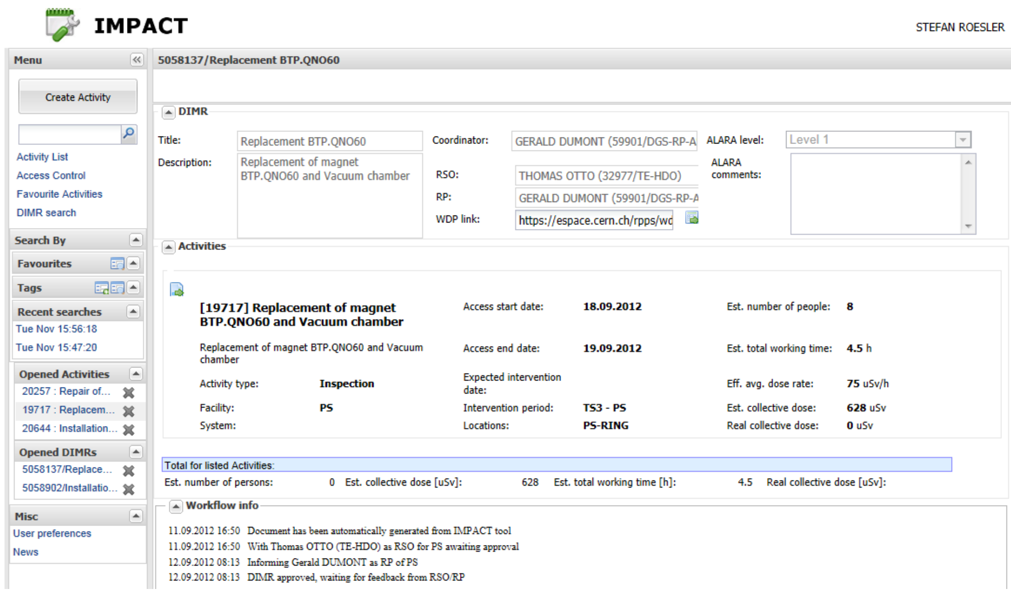
Activité surfacique spécifique CA :

10 CS | 100 CS

niveau I | niveau II | niveau III

Optimization – *ALARA procedure*

Work- and dose planning (DIMR)



Replacement of BTP.QNO60

							Working time [man.hours]	Effective avg. dose rate [µSv/h]	Collective dose [man.µSv]	Collective dose [man.µSv]	Working time real [man.hours]	Collective real dose [man.µSv]	Collective real dose [man.µSv]	
						Totals:	8.5	74	628	628	0	1009	1009	
Prior intervention To be completed and checked by work coordinator(s) and experts								Prior intervention To be checked and completed by RP			Posterior intervention To be completed by work coordinator or/and RP			
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
No.	Work description (Task)	Responsible person	Dep/Grp (executing)	WorkTeam	Location (check table 'DoseRates')	Persons [No.]	Exposure time [min]	Dose rate [µSv/h]	Estimated dose [µSv]	Estimated total dose [µSv]	Real time [min]	Real dose [µSv]	Real total dose [µSv]	Remarks
1	**Preparation**									26			34	
1.01	Transport new magnet to BTP via Door 111	Y. Bernard	EN/HE	Team 1	D	2	15	25	13			14		
1.02	Vent BTP sector with N2	P. Demarest	TE/VSC	Team 5	C	2	10	40	13			20		
2	**Removal**									183			299	
2.01	Disconnect magnet QN060 (Covers, Power & Water)	A. Newborough	TE/MSC	Team 2	E	2	10	75	25			67		
2.02	Disconnect / Split corrector magnet	A. Newborough	TE/MSC	Team 2	F	2	30	100	100			57		
2.03	Disconnect vac clamps	P. Demarest	TE/VSC	Team 5	E	2	5	75	13			42		
2.04	Disconnect magnet supports	A. Newborough	TE/MSC	Team 2	E	2	5	75	13			53		
2.05	Remove Existing Magnet - (Crane/Forklift)	Y. Bernard	EN/HE	Team 1	E	2	5	75	13			48		
2.06	Transport old Magnet for storage - Crane	Y. Bernard	EN/HE	Team 1	D	2	15	25	13			22		
2.07	Supervision magnet work	A. Newborough	TE/MSC	Team 3	B	1	15	30	8			10		
3	**Reinstallation**									295			357	
3.01	Position new magnet - (Crane/Forklift)	Y. Bernard	EN/HE	Team 1	E	2	10	75	25			18		
3.02	Reconnect magnet supports	A. Newborough	TE/MSC	Team 2	E	2	5	75	13			17		
3.03	Re-assemble corrector magnet	A. Newborough	TE/MSC	Team 2	F	2	45	100	150			23		
3.04	Survey into position	T. Dobers	BE/ABP	Team 4	F	2	15	100	50			124		
3.05	Install vacuum chamber with new seals	P. Demarest	TE/VSC	Team 5	E	2	10	75	25			37		

Optimization during design – *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, *etc.*)
   - identify if remote handling is possible

Start of iteration:

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

Optimization during design – *Intervention doses*

Example: inner triplet disassembly
(presented at the LHC IR Upgrade Phase I, TDG Meeting, 04-12-2008)

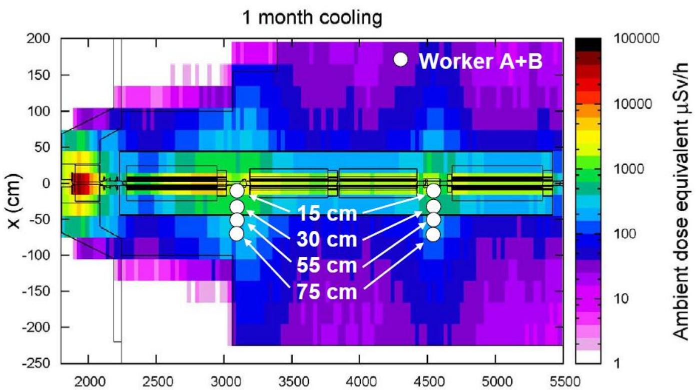
Two options:

1. Grinding tool
   + precise, no damage to magnets
   - slow, dust, smoke

2. Remote controlled cutter
   + fast, no splints or dust
   - damage to instrumentation and magnets

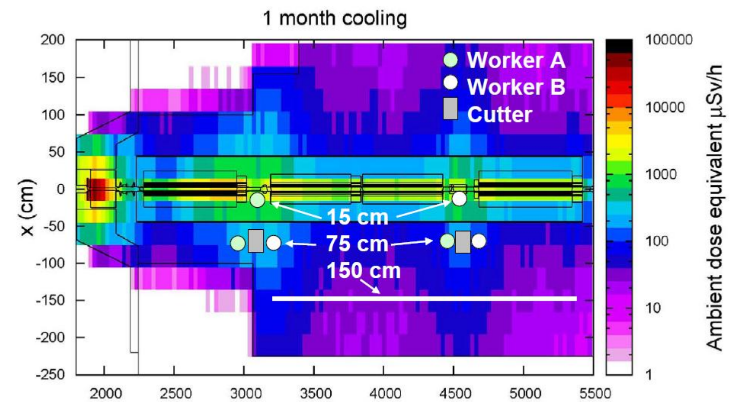
Optimization during design – *Intervention doses*

Option 1: Grinding tool



Distance to beam line cm	Working steps	Number of persons	Time h	Cooling time 1 month D mSv/person	Cooling time 4 month D mSv/person
75	Dismounting the tie - rods	2	1.0	0.12	0.05
	Dismounting the outside sleeve	2	3.0	0.35	0.16
	Removing the 2 MLI thermal shield blanket	2	0.2	0.02	0.01
	Dismounting the thermal shield	2	7.5	0.87	0.41
	Removing the 1 MLI radiative blanket	2	0.2	0.02	0.01
	Removing the supports: Spacer+ thermal shield	2	0.8	0.09	0.04
55	Cut to open FF	2	6.0	1.69	0.76
	Cut to open XBt	2	6.0	1.69	0.76
30	Cut to open XB	2	12.0	5.07	2.27
	Cut to open CY	2	6.0	2.53	1.14
	Cut to open M1, M2, M4	2	18.0	7.60	3.41
	De - braze bus bars (13 kA) M4	2	6.0	2.53	1.14
	Disconnect spools connections M4	2	3.0	1.27	0.57
	Remove QH, VT, thermometers, heaters, ... from M2	2	6.0	2.53	1.14
	Cut to open V	2	6.0	2.53	1.14
	Remove 2 flexible CC'	2	4.0	1.69	0.76
15	Cut to open LD1	2	6.0	4.45	1.95
	Cut to open EE	2	6.0	4.45	1.95
		Individual dose		39	18
		Collective dose		79	35

Option 2: Remote controlled cutter



Distance to beam cm	Working steps	Number of persons	Time h	Cooling time 1 month D mSv/person	Cooling time 4 month D mSv/person
75	Dismounting the tie - rods	2	1.0	0.12	0.05
	Dismounting the outside sleeve	2	3.0	0.35	0.16
	Removing the 2 MALI thermal shield blanket	2	0.2	0.02	0.01
	Dismounting the thermal shield	2	7.5	0.87	0.41
	Removing the 1 MLI radiative blanket	2	0.2	0.02	0.01
	Removing the supports: Spacer+ thermal shield	2	0.8	0.09	0.04
150	Aisle	2	0.5	0.01	0.00
75	Installing the remote controlled cutter 2x	2	1.0	0.12	0.05
	Cutting				
75	Removing the remote controlled cutter 2x	2	1.0	0.12	0.05
150	Aisle	2	0.5	0.01	0.00
15	Inspection Q1-Q2	1	0.2	0.10	0.04
15	Inspection Q2-Q3	1	0.2	0.14	0.06
		Individual dose		**2.00**	**0.90**
		Collective dose		**3.70**	**1.70**

Option 1 clearly excluded!

Courtesy: M.Fuerstner

Optimization during design – *Material choice*

Goal:
- Minimize doses received by personnel during maintenance and repair
- Reduce costs for waste disposal

→ Consider radiological hazards in the choice of construction materials

Tool to optimize material choices:

ActiWiz

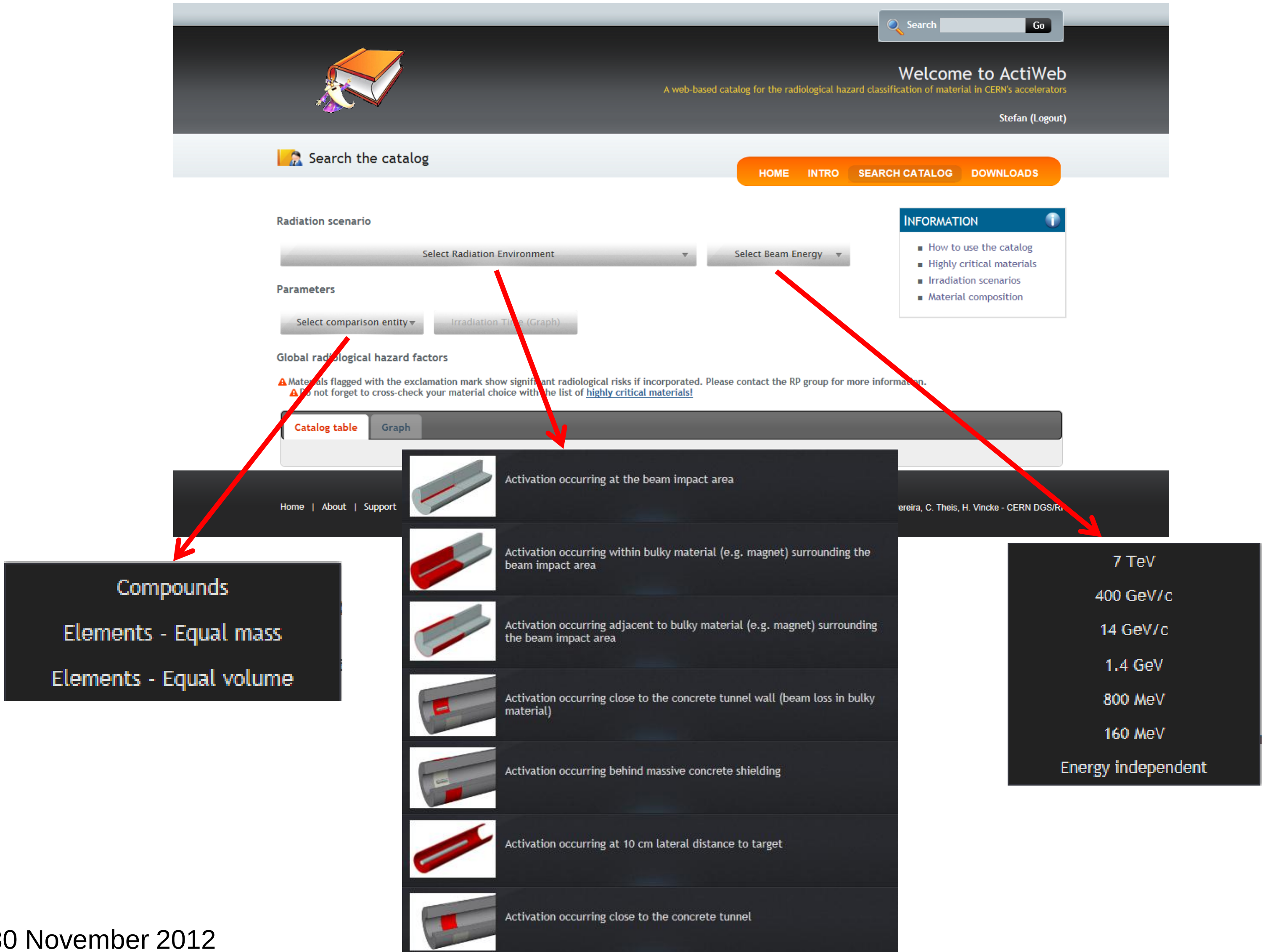
(Authors: **C.Theis and Helmut Vincke**)

- 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*

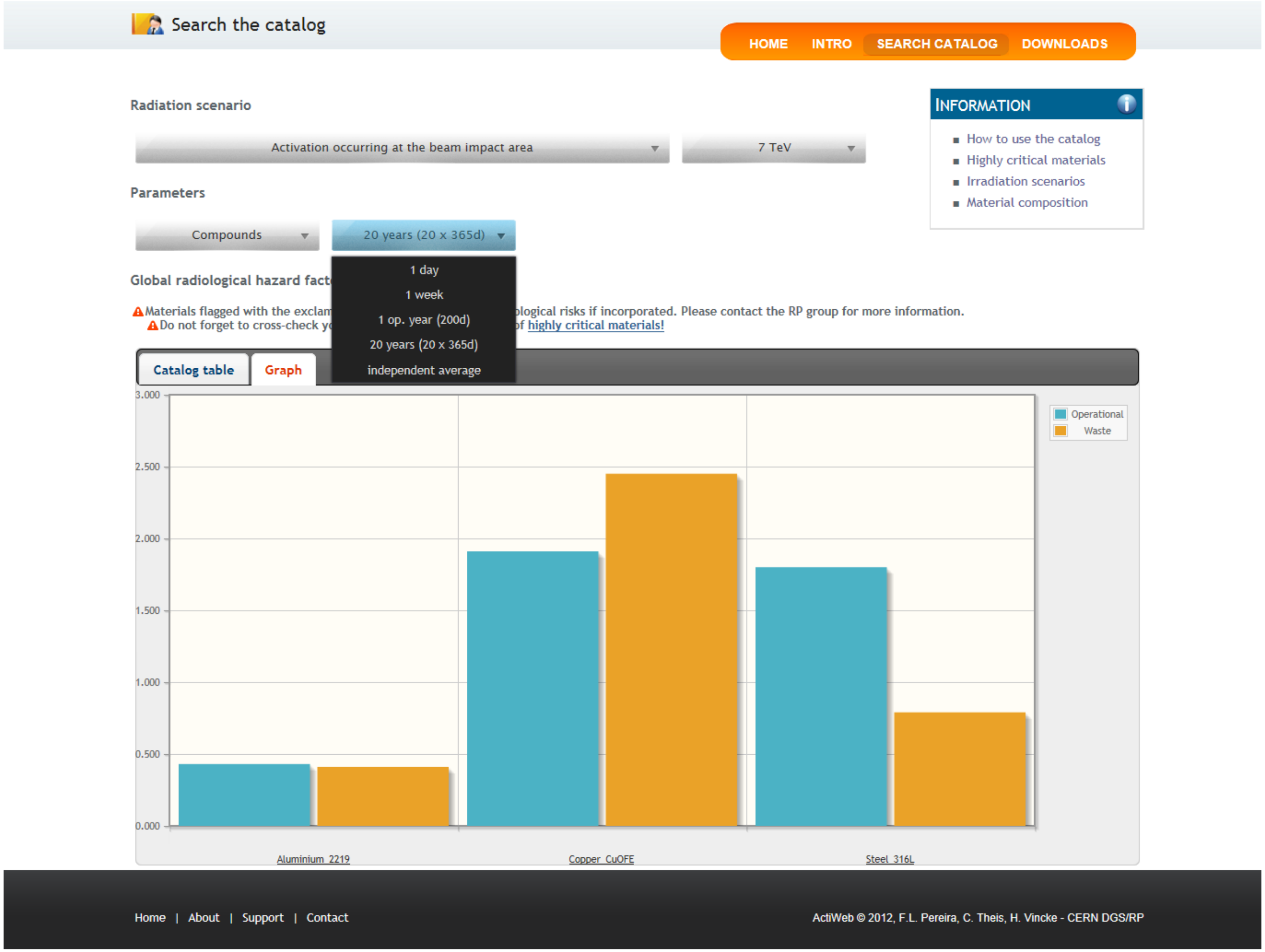


Optimization during design – *ActiWiz*

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*



Summary

LS3 dismantling activities:

- Activation and residual dose rates will increase from LS1 until LS3 by factors between 8 and 16.
- LSS1 and LSS5 will become Limited Stay Areas until LS3 with residual dose rates (few months cooling) in the aisle of about 100 µSv/h, reaching several mSv/h close to most radioactive objects.
- Thus, the total duration of stay of a person in the area during one year must not be more than ~2 days (to stay below an individual annual dose of ~2mSv).
- Development of tools and work procedures for dismantling should be studied in parallel to the upgrade as it may affect the length of LS3. Related experience should be considered in the design for HiLumi LHC.

Optimization of HiLumi design

- As successfully done during the LHC design, all components to be installed in high-loss regions (*e.g.*, LSS1 and LSS5) must be optimized for future handling and radioactive waste disposal (material choice and technology).
- Radiological assessments, including detailed FLUKA calculations, will be performed as soon as design choices have been made which may then serve as input to assess design options.