Evolution of V_D and I_{LEAK} of the ATLAS barrel SCT

(Version 8)

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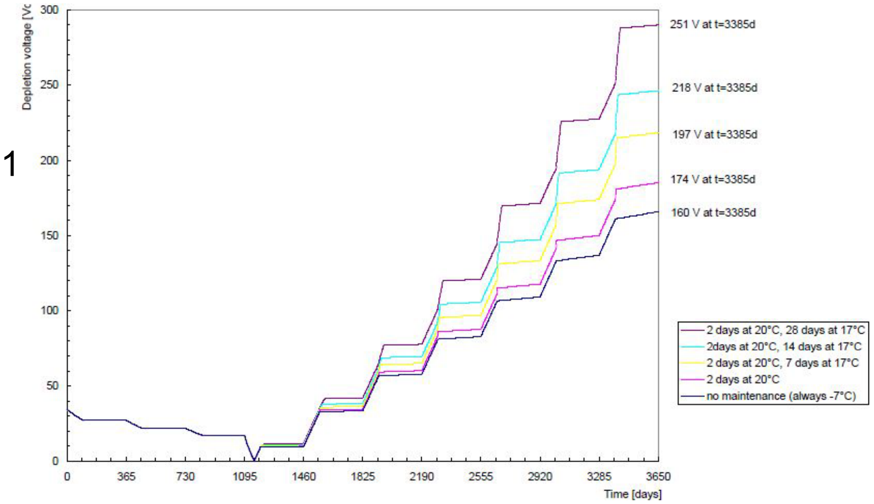
[1] Reproduction of the ATLAS ID-TDR results

Assumptions of TDR fig.11-4:

- Total fluence = $1.4 * 10^{14}\ n_{eq}/cm^2$ for 10 years
- First 3 years at 10^{33}, later 7 years at $10^{34}\ cm^{-2}s^{-1}$
- 100 days for beam, access right after.

Access scenario			V_D at 3385th day	
Rest	Access 1	Access 2	TDR	our
- 7°C	2 days at 20°C	28 days at 17°C	251 V	289 V
		14 days at 17°C	218 V	237 V
		7 days at 17°C	197 V	208 V
		none	174 V	179 V
	none	none	160 V	164 V

TDR results are more or less reproducible.



ATLAS ID-TDR Figure 11-4

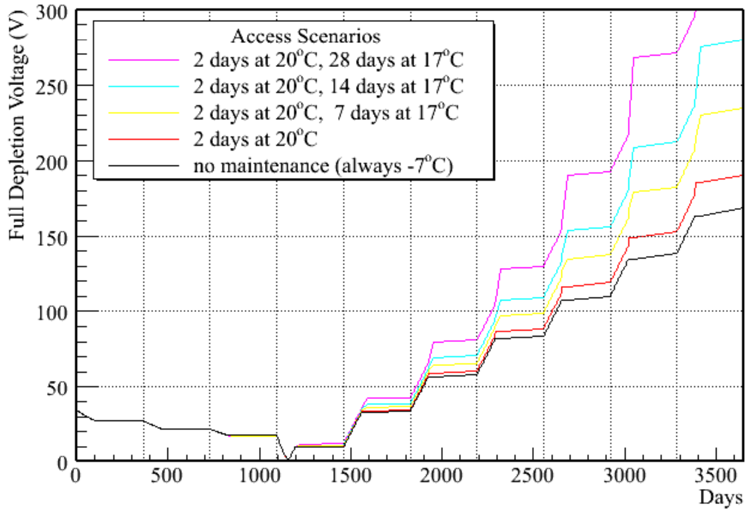


Fig.1: present re-calculation

[2] Updating the basic parameters

Sensor parameters must be updated since TDR:

- Sensor thickness : 300 μm at TDR → 285 μm [1]
- Sensitive area (Barrel) : (width)80μm*768=61.440mm, (length)61.360mm
- Initial depletion voltage : 34 V at TDR → 65 V [2]

Thus, N_{eff0} is set to $1.026*10^{12}$ cm^{-3} to reach 65V.

Neutron equivalent fluence at the Barrel layers

$1.3*10^{14}$ n_{eq} /cm^2/730fb^{-1} @SCT-B3 at ID TDR → new results below [3]

layer	R (cm)	Z(cm)	n_{eq} fluences (cm^{-2})/100fb^{-1}
Pixel B-layer	4.2	0-40.7	$267*10^{12}$
Pixel B2	12.7	0-40.7	$46*10^{12}$
SCT B3	30	0-75	$16*10^{12}$
SCT B6	52	0-75	$8.9*10^{12}$
SCT D9	44-56	272	$14*10^{12}$

[1] ATLAS SCT Specification
[2] NIMA 578 (2007) 98–118
[3] Table5.3 of ATLAS-GEN-2005-001

[3] New luminosity profile and ATLAS radiation level

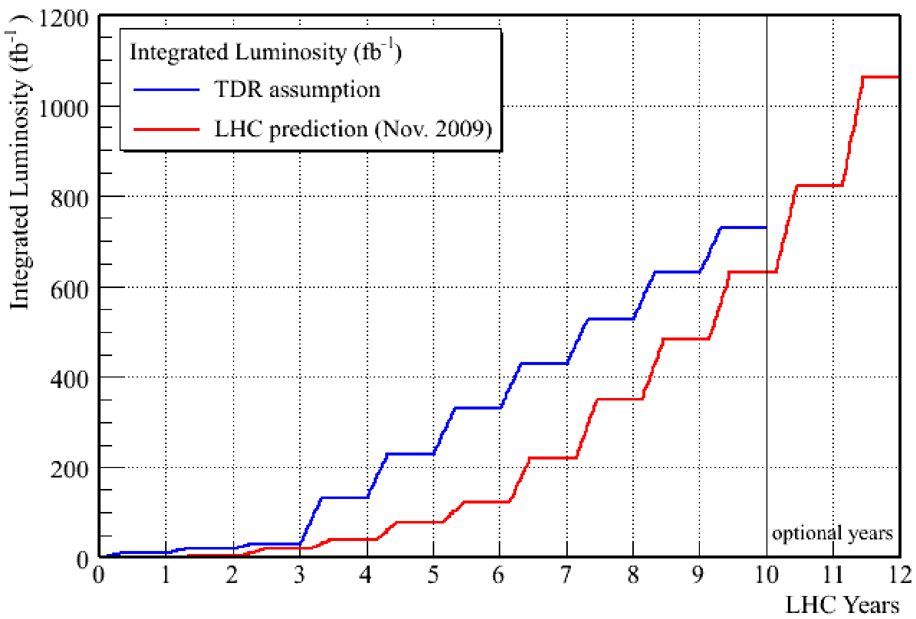


Fig. 2: Integrated luminosity

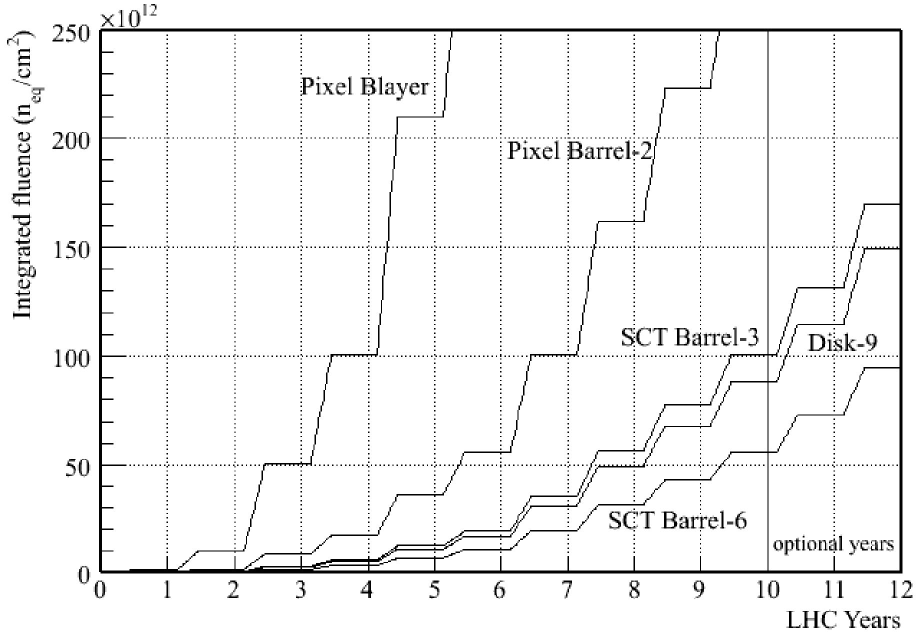


Fig. 3: n_{eq}-Fluenece

Prediction of LHC Luminosity profile [1]													
year	1 2010	2 2011	3 2012	4 2013	5 2014	6 2015	7 2016	8 2017	9 2018	10 2019	11 2020	12 2021	year
IL/year	0.5	3.3	15	19	41	42	99	132	132	145	193	242	fb^{-1}
Integ. L	0.5	3.8	19	38	79	121	220	352	484	629	822	1064	fb^{-1}

[1] from talk given by F. Zimmermann at ATLAS Upgrade Week, Nov.9-13, 2009

[4] New access conditions and cooling scenarios

Assuming possible cooling system upgrade in the end of 3rd year, various cooling scenarios are considered.

	T_{sensor}(°C) for 1st 3 years					T_{sensor}(°C) for next 9 years				
SCT	on	on	on	maintenance	on	on	on	on	maintenance	on
Beam	off	on	off		off	off	on	off		off
days	50	116	50	23	126	50	116	50	23	126
A	-7	-7	-7	+20	-22	-7	-7	-7	+20	-22
B	0	0	0	+20	-15					
C	+7	+7	+7	+20	-8					
D	+15	+15	+15	+20	0					
E	+25	+25	+25	+20	+10					
F	0	0	0	+20	-15	-15	-15	-15	+20	-30
G						-10	-10	-10	+20	-25
H						-5	-5	-5	+20	-20
I						0	0	0	+20	-15
J (*)	+5	+5	+5	+20	+5	+5	+5	+5	+20	+5

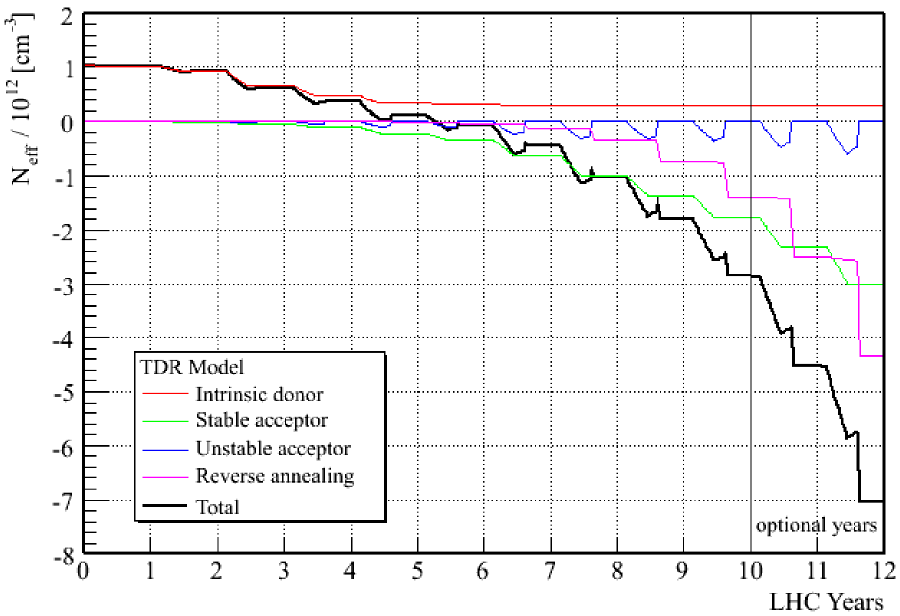
(*) Scenario-J is set specially for the Barrel-6 case.

[5] Radiation damage models and parameters for V_D calculation

	TDR model	Hamburg model
Donor removal	$N_{eff,0} - N_{C0}\left(1-e^{-c\Phi}\right)$	$N_{eff,0} - N_{C0}\left(1-e^{-c\Phi}\right)$
Unstable acceptor	$-g_S\Phi\exp(-t/\tau(T))$, $\tau(\mathrm{T}) = \tau_0\exp(-0.175\cdot T[°\mathrm{C}])$	$-g_a\Phi\exp\left(-\Theta(T)_a t/\tau_a\right)$, $\Theta(T)_a = \exp\left(\frac{E_a}{k_B}[1/T_R - 1/T]\right)$
Stable acceptor	$-g_C\Phi$	$-g_C\Phi$
Reverse annealing	$-g_y\Phi\left(1-\frac{1}{1+k_0 e^{-E_a/k_B T}\cdot g_y\Phi\cdot t}\right)$	$-g_y\Phi\left(1-1/(1+\Theta(T)_y t/\tau_y)\right)$, $\Theta(T)_y = \exp\left(\frac{E_y}{k_B}[1/T_R - 1/T]\right)$
Parameters	$N_{C0} = 0.70\times N_{eff,0}$ $c = 2.29\times10^{-13}\ \mathrm{cm}^2$ $g_S = 0.0193\ \mathrm{cm}^{-1}$ $\tau_0 = 70$ days $g_C = 0.0177\ \mathrm{cm}^{-1}$ $g_y = 0.046\ \mathrm{cm}^{-1}$ $k_0 = 520\ \mathrm{cm}^3\mathrm{s}^{-1}$ $E_a = 1.31$ eV $N_{eff,0} = 1.026\times10^{12}\ \mathrm{cm}^{-3}$	$N_{C0} = 0.70\times N_{eff,0}$ $c = 0.075\ \mathrm{cm}^{-1}/N_{C0}$ $g_a = 0.018\ \mathrm{cm}^{-1}$ $\tau_a = 2.29$ days ($20°\mathrm{C} \equiv \mathrm{T_R}$) $E_a = 1.09$ eV $g_C = 0.017\ \mathrm{cm}^{-1}$ $g_y = 0.059\ \mathrm{cm}^{-1}$ $\tau_y = 480$ days (20°C) $E_y = 1.33$ eV $N_{eff,0} = 1.026\times10^{12}\ \mathrm{cm}^{-3}$
references	ATLAS Inner Detector TDR (1997), Vol-II, p. 402, Table 11-5	G. Lindstrom et al., NIM A 466(2001) 308-326

Evolution of effective doping concentration N_{eff}

cooling scenario B, Barrel-3



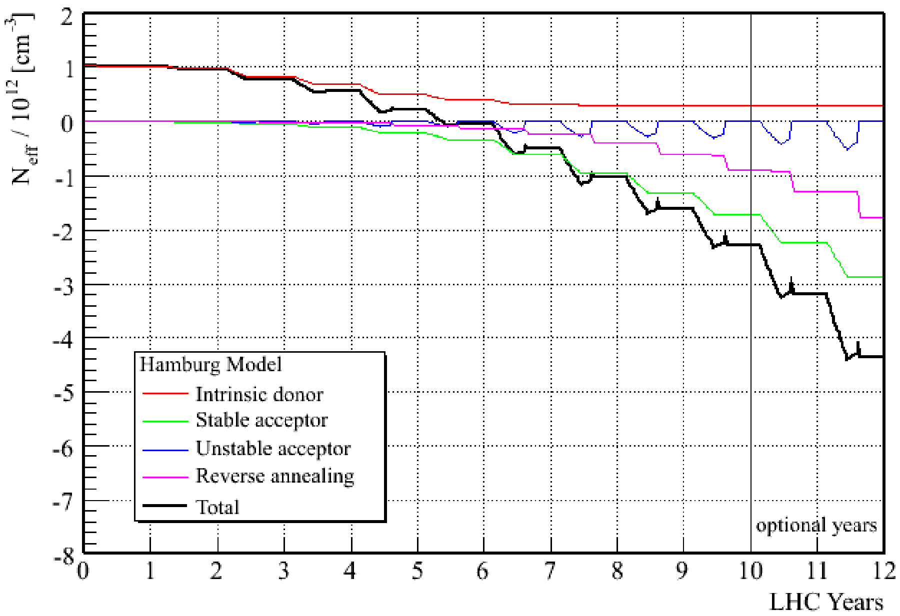


Fig.4 : TDR model (2nd order)

Fig.5 : Hamburg model (1st order)

Reverse annealing (pink) takes over in later years.

Stable acceptor (green) is dominating.

[6] Full depletion voltage V_D

with cooling scenario A, Barrel-3

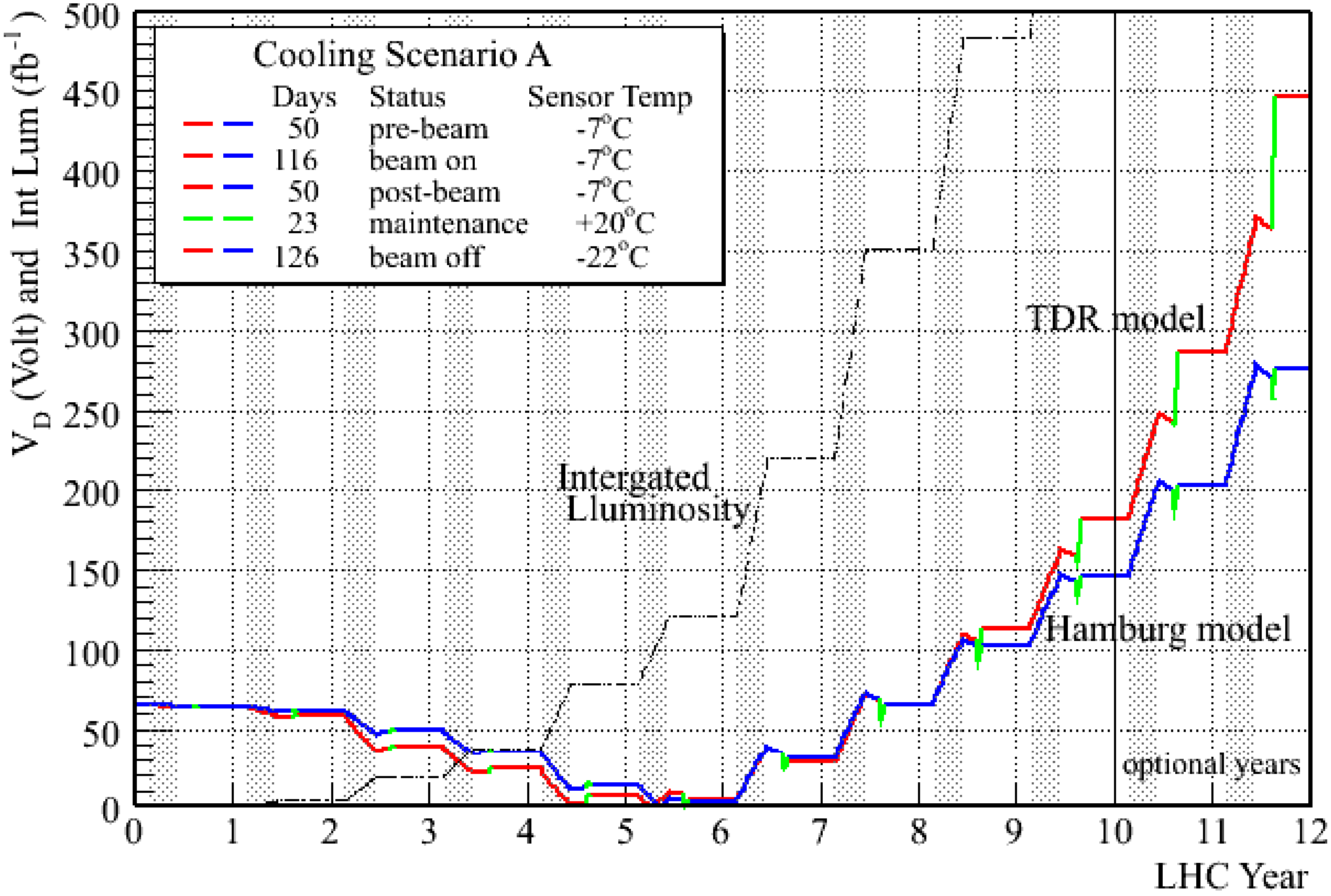


Fig.6 : Full depletion voltage of cooling scenario A.

Cooling scenario dependence of V_D

Barrel-3

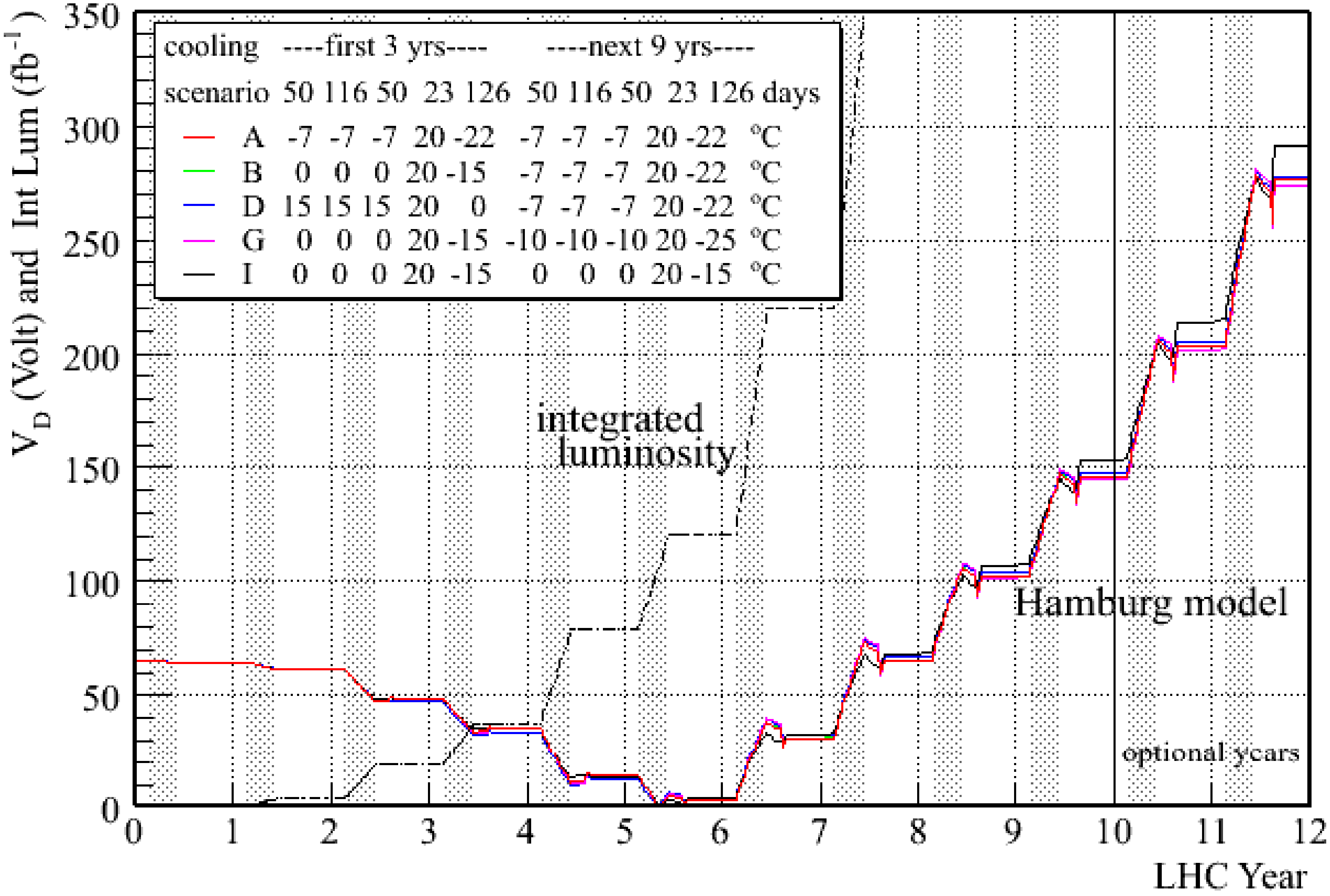


Fig.7 : Vd for cooling scenarios A, B, D, G and I

Differences caused by protons and neutrons

Radiation damage by protons is different from that by neutrons[1]. See the right table.

	by neutrons	by protons	Hamburg model
g_C [cm^{-1}]	0.015	0.019	0.017
g_Y [cm^{-1}]	0.052	0.066	0.059

The plot shows the V_d evolution assuming these damage constants, while keeping the fluence values same.

Note the n-eq flux ratios are [2]

location	neutrons	pions	protons
B3	8.4	6.4	1.1
B6	5.8	2.6	0.52
D9	9.3	3.5	0.91

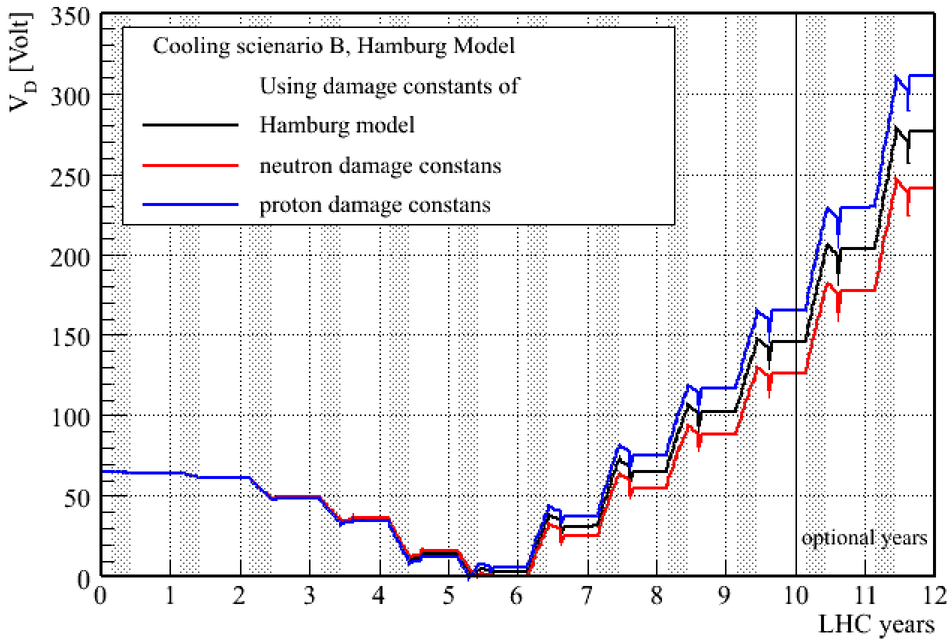


Fig. 8 : dependence on damage constants

[1] G. Lindstrom et al., NIMA 466(2001)308
[2] Table5.3 of ATLAS-GEN-2005-001

V_D evolution with various cooling scenarios at Barrel-3

	T_{sensor}(°C) for 1st 3 years					T_{sensor}(°C) for next 9 years					model	V_D (volt) at the year end of			
days	50	116	50	23	126	50	116	50	23	126		6th	8th	10th	12th
A	-7	-7	-7	20	-22	-7	-7	-7	20	-22	TDR	4.1	64.6	181	447
											Hamburg	2.9	65.3	146	276
B	0	0	0	20	-15						TDR	4.1	64.6	181	447
											Hamburg	2.9	65.4	146	276
C	7	7	7	20	-8						TDR	4.1	64.7	181.4	446.6
											Hamburg	3.2	65.6	146	277
D	15	15	15	20	0						TDR	4.2	64.7	181	447
											Hamburg	4.4	66.8	147	278
E	25	25	25	20	10						TDR	4.5	65.1	182	447
											Hamburg	11.9	74.4	155	285
F	0	0	0	20	-15	-15	-15	-15	20	-30	TDR	4.0	64.1	179	438
											Hamburg	2.7	64.7	144	273
G						-10	-10	-10	20	-25	TDR	4.1	64.3	180	441
											Hamburg	2.8	65.0	145	274
H						-5	-5	-5	20	-20	TDR	4.1	65	183	452
											Hamburg	3.1	65.8	147	279
I						0	0	0	20	-15	TDR	4.4	67.0	192	483
											Hamburg	3.8	68.3	153	291

[7] Bulk leakage current

references	Robert Harper's Thesis (2001, University of Sheffield)

$$I = g(\Theta(T_A)t_{ir}, \Theta(T_A)t^{'})\alpha\phi V$$

$$g(\Theta(T_A)t_{ir}, \Theta(T_A)t^{'}) = \sum_{i=1}^{n}\left\{A_i \frac{\tau_i}{\Theta(T_A)t_{ir}}\left[1-\exp\left(-\frac{\Theta(T_A)t_{ir}}{\tau_i}\right)\right]\exp\left(-\frac{\Theta(T_A)t^{'}}{\tau_i}\right)\right\}$$

$$\Theta(T_A) = \exp\left(\frac{E_I}{k_B}\left[\frac{1}{T_R}-\frac{1}{T_A}\right]\right)$$

$$\alpha_{eq}(-7°C) = (6.90 \pm 0.20)\times 10^{-18}\ \mathrm{A \cdot cm^{-1}}$$

i	τ_i (min)	A_i
1	$(1.2 \pm 0.2)\times 10^{6}$	0.42 ± 0.11
2	$(4.1 \pm 0.6)\times 10^{4}$	0.10 ± 0.01
3	$(3.7 \pm 0.3)\times 10^{3}$	0.23 ± 0.02
4	124 ± 25	0.21 ± 0.02
5	8 ± 5	0.04 ± 0.03

Leakage current/module at B3

	T_{sensor}(°C) for 1st 3 years					T_{sensor}(°C) for next 9 years					I_{leak}(mA) of B3 at the year end of				
days	50	116	50	23	126	50	116	50	23	126	T(°C)	6th	8th	10th	12th
A	-7	-7	-7	+20	-22						-7	0.24	0.69	1.19	1.98
B	0	0	0	+20	-15						-7	0.24	0.69	1.19	1.98
C	+7	+7	+7	+20	-8	-7	-7	-7	+20	-22	-7	0.24	0.69	1.19	1.98
D	+15	+15	+15	+20	0						-7	0.24	0.69	1.19	1.98
E	+25	+25	+25	+20	+10						-7	0.23	0.68	1.18	1.97
F						-15	-15	-15	+20	-30	-15	0.11	0.31	0.53	0.88
											-7	0.24	0.70	1.20	2.00
G						-10	-10	-10	+20	-25	-10	0.18	0.51	0.89	1.47
	0	0	0	+20	-15						-7	0.24	0.69	1.20	1.99
H						-5	-5	-5	+20	-20	-5	0.29	0.84	1.44	2.40
											-7	0.24	0.69	1.18	1.97
I						0	0	0	+20	-15	0	0.46	1.33	2.28	3.79
											-7	0.23	0.68	1.16	1.92

[9] Bulk leakage current

Barrel-3 for various cooling scenarios based on Harper's model.

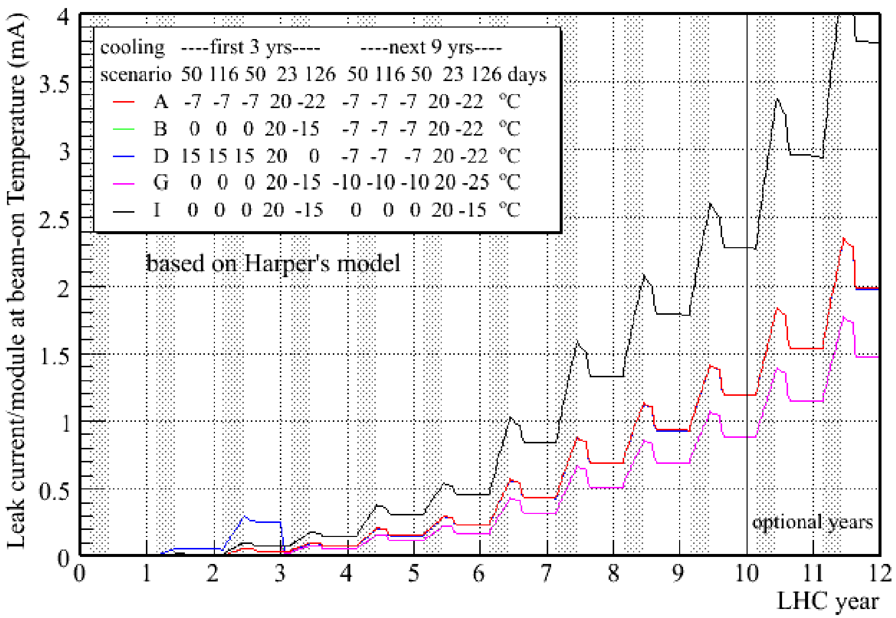


Fig. 9 : Leakage current at the operating temperature

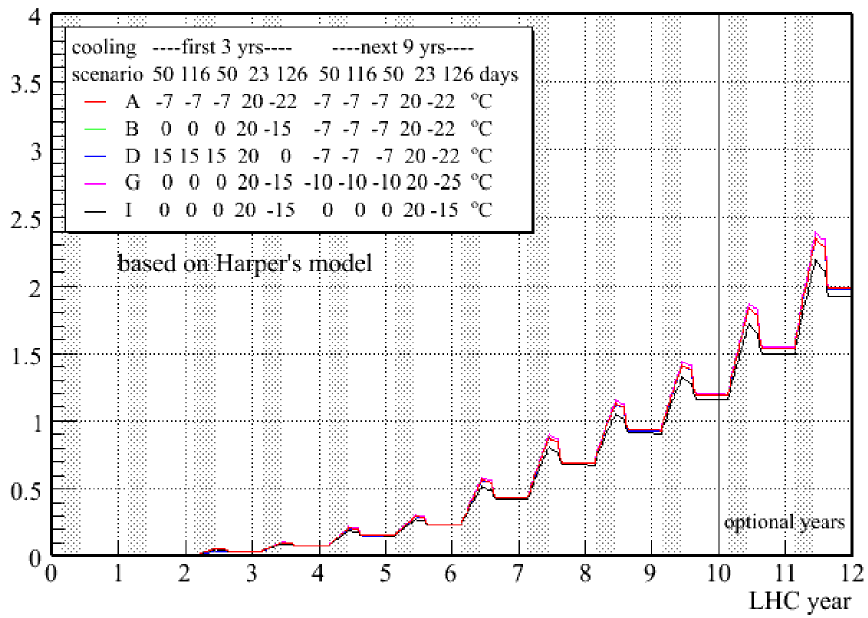


Fig. 10 : Leakage current normalized at -7°C

Bulk leakage current: comparison with Moll's model [1]

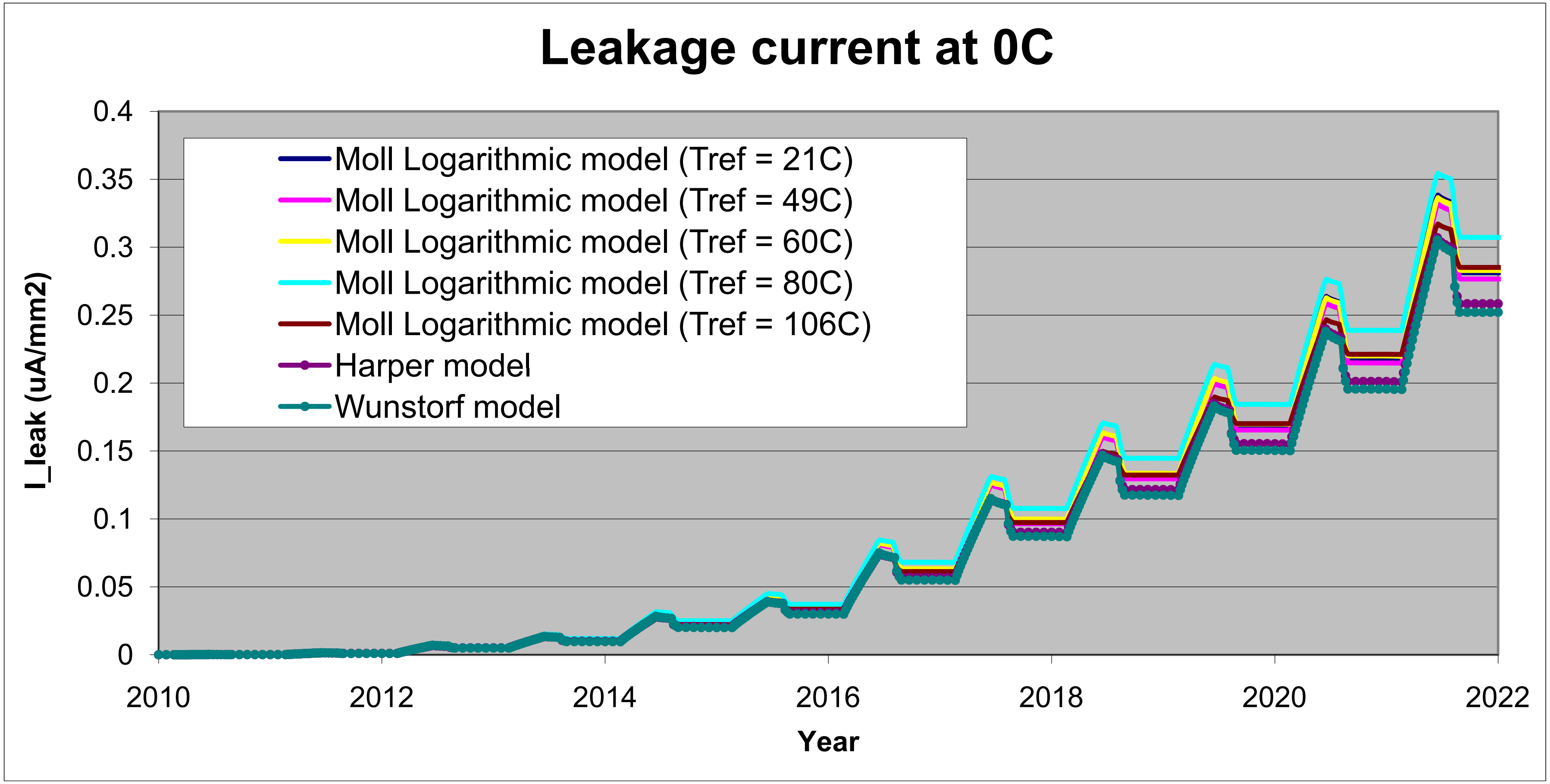


Fig. 11: Both models on leakage current agree within +-10%.

[1] Moll Logarithmic model: M. Moll et al., NIM A426(1999)87
[2] Harper model: Robert Harper's Thesis (2001, University of Sheffield)
[3] Wunstorf model: R. Wunstorf, PhD Thesis (Oct. 1992, University of Hamburg) and A Chilingarov et al., NIM A360 (1995) 432-437

[8] HV(sensor bias voltage) profiles

HV-case-A : V_{HV} set at least 100V higher than Vd (but V_{min} is150V).
An unique fixed HV setting for each year is assumed.

HV-case-B : V_{HV} set at the maximum voltage of 430 V.

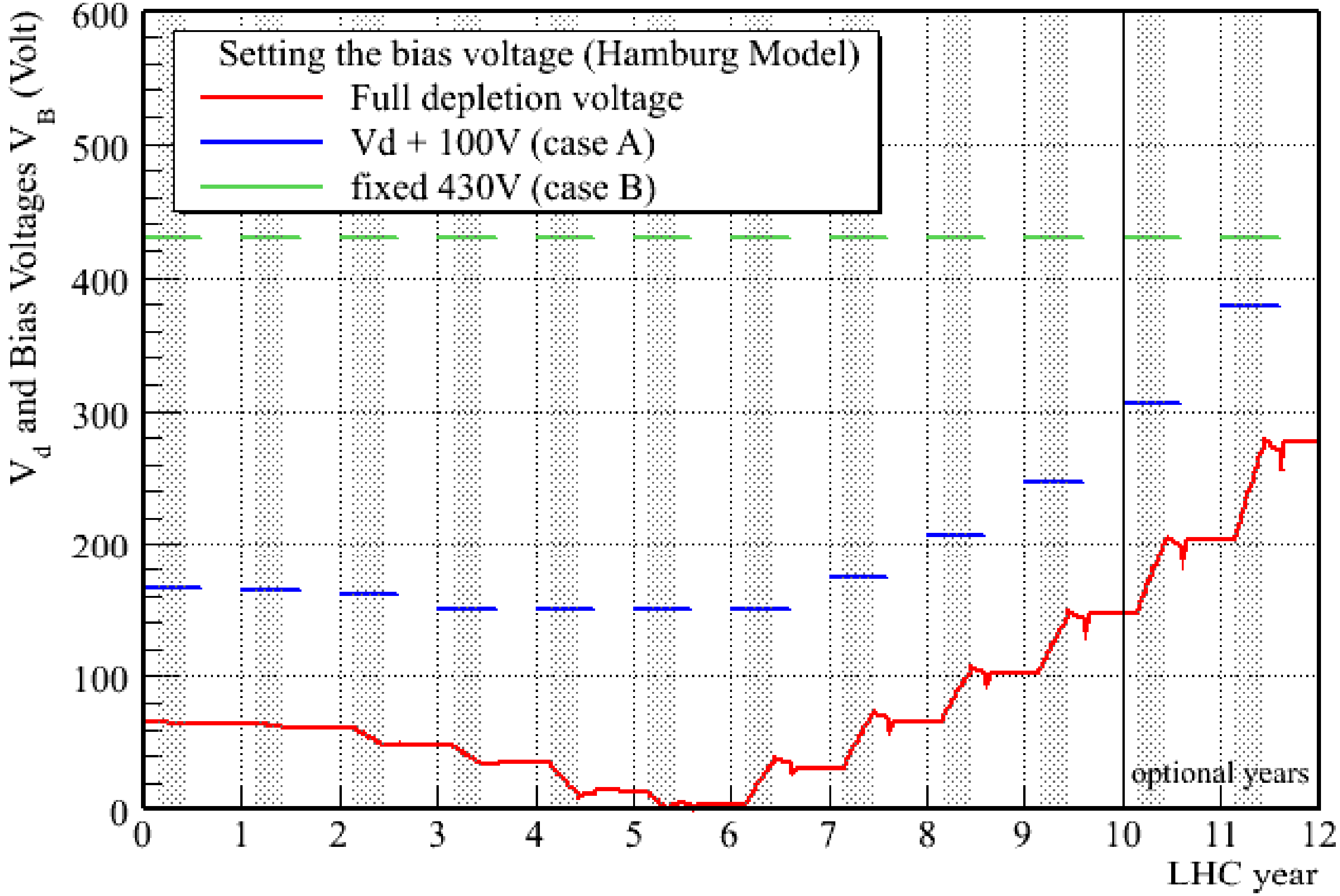
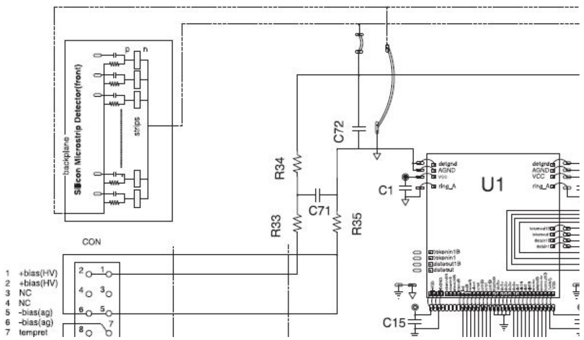


Fig.12 : Setting values of bias voltages

Voltage drop across the R_{HV}(11.2kΩ) of the module

SCT Barrel-3



Values of HV resisters on hybrid [1]
R33, R34 = 5.1 kΩ, R35 = 1 kΩ

[1] Fig. 7 of A. Abdesselam et al.,NIM A568(2006)642

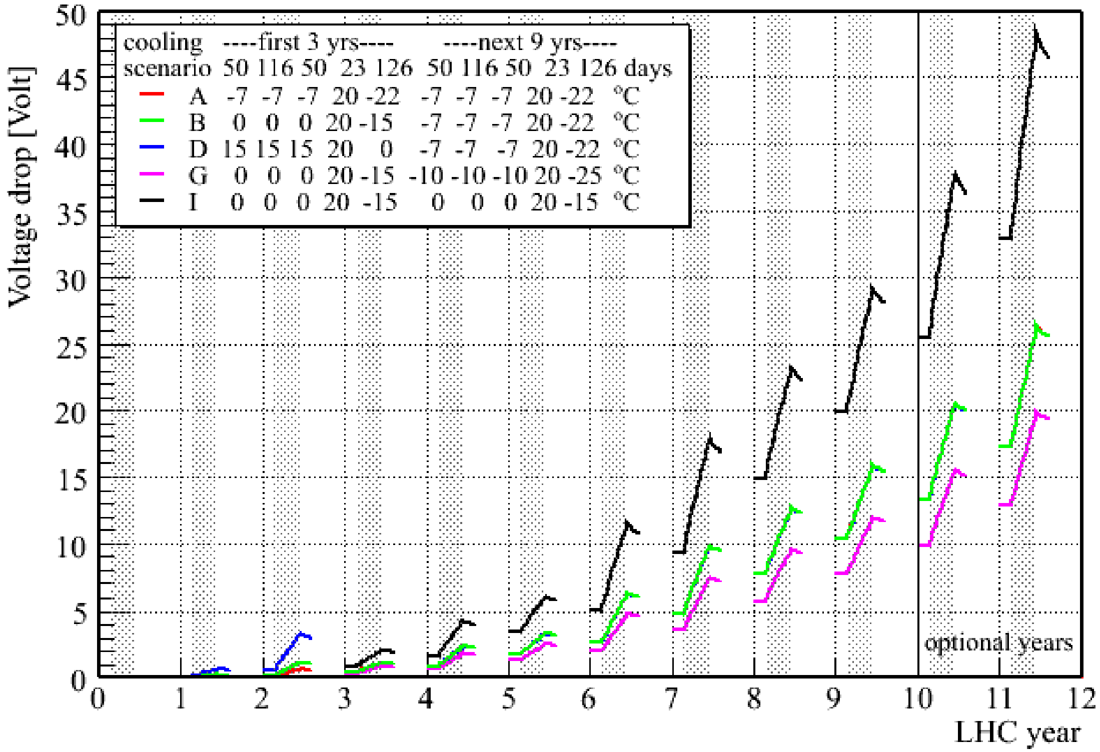


Fig.13 : Voltage drop across the HV resistors on the module

[9] Power dissipation on the sensors

$$Power = V_{apply} * I_{leak}$$

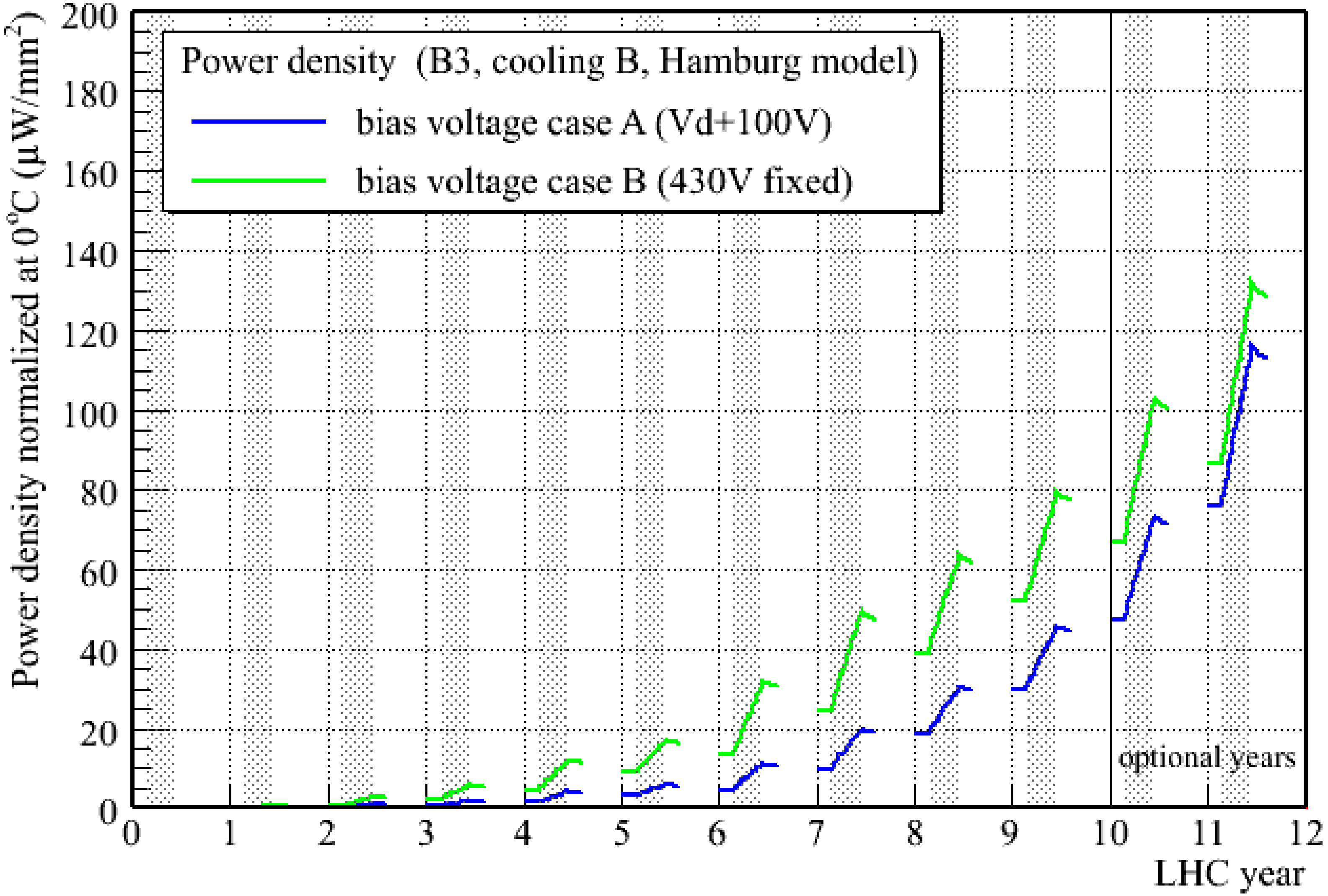


Fig. 14 : Power density normalized at T=0°C

Total power dissipation by leak current at Barrel-3

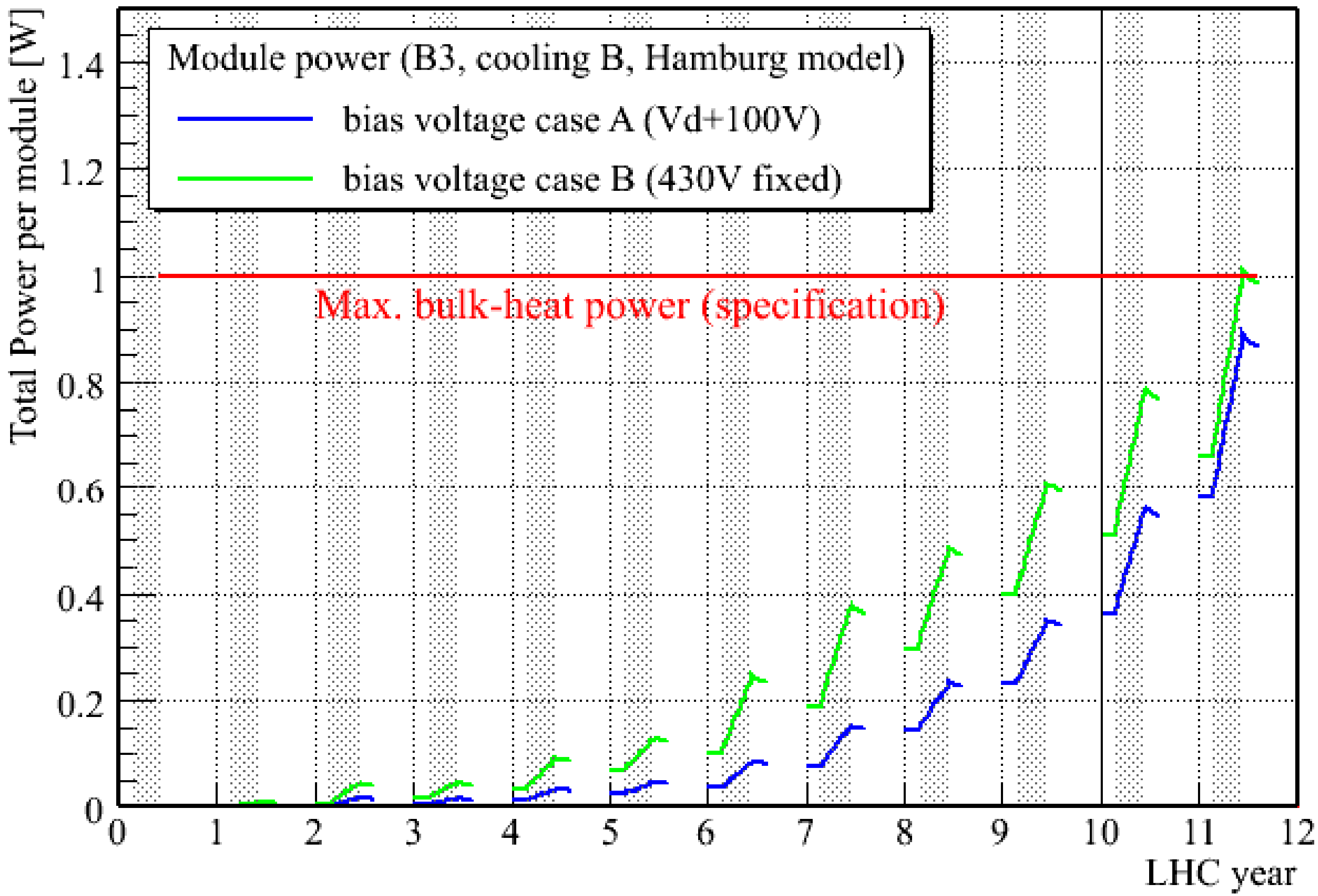
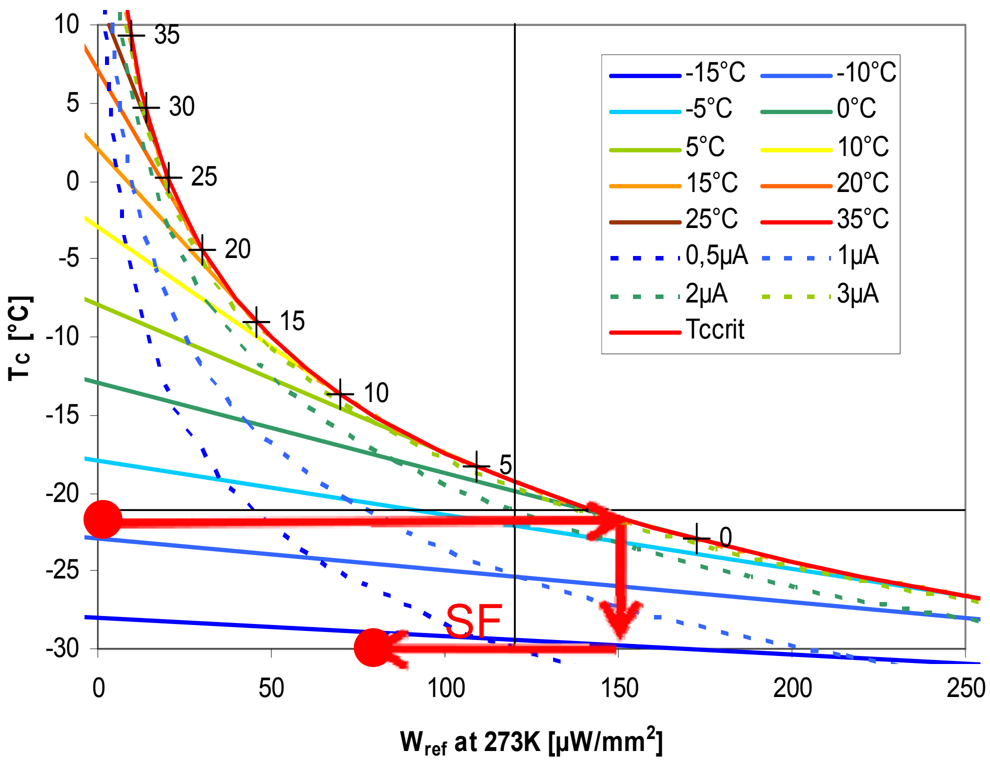


Fig. 15 : Total power dissipation per module

[10] Thermal runaway limits

Thermal simulation using FEA as well as simple model by G. Beck and G. Viehhauser (see Glasgow workshop 14/05/2009 and draft paper to be published.)



Thermal runaway limits in bulk heat generation versus T_C plane.

How to calculate the runaway time?"

(1) Pick up coolant temperature T_C (say -22^{o}C) for the next 9 years (T_C=-15^{o}C fixed for the first 3 years).

(2) Calculate the thermal runaway critical point from the red curve (150uW/mm^2).

(3) Divide by the safety factor SF (say 2) to get the critical power density q_0 (75uW/mm^2).

(4) Calculate the time reaching the corresponding q_0 .

Cooling temperature of B3 vs LHC year

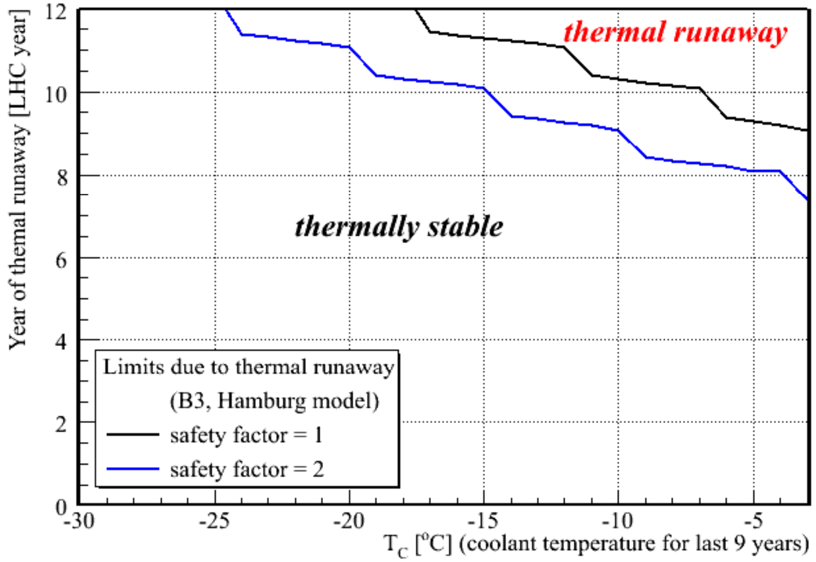
The coolant temperature T_C is set at fixed value for last 9 years.

$$\text{safety factor} \equiv \frac{\text{critical power density}}{\text{actual power density}}$$

Fig. 16 : runaway year as a function of T_C

Fig. 17 : T_C versus LHC year

Fig. 18 : safety factors for scenarios G,H and I



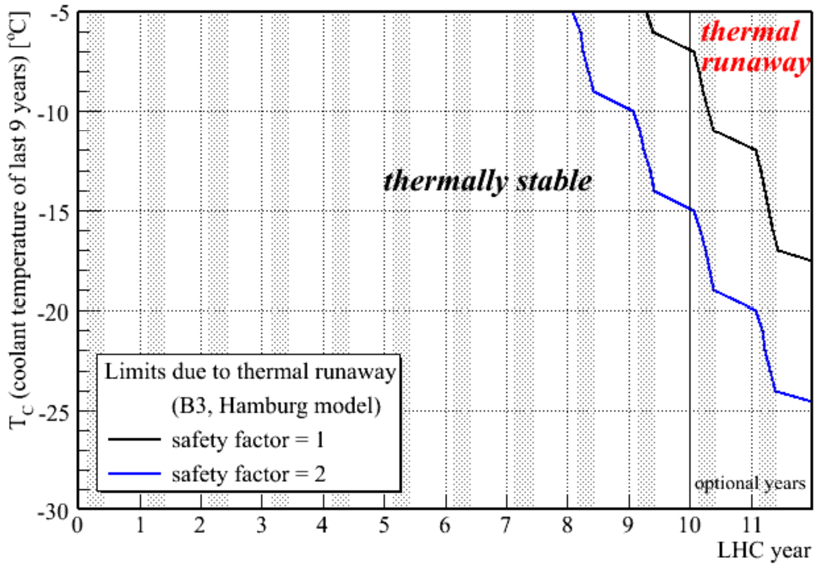


Fig. 17

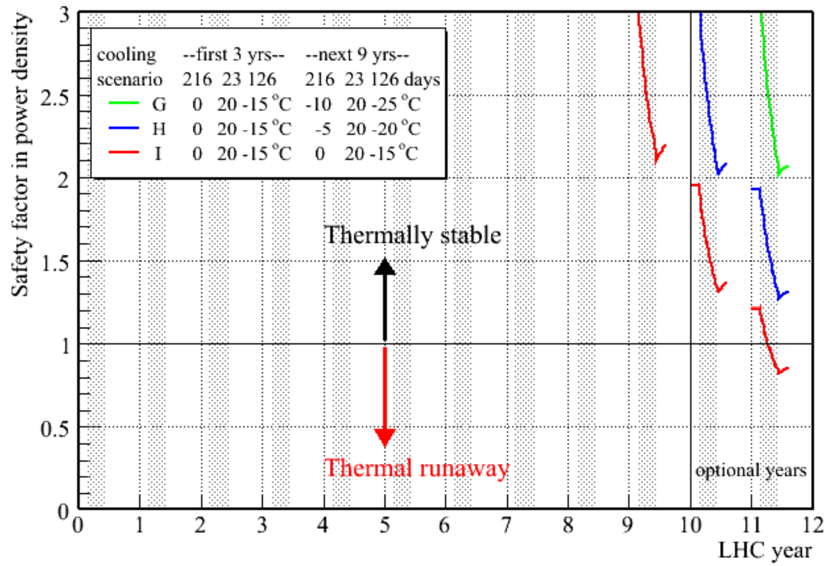


Fig. 18

[11] Dependence on maintenance days

Duration of the annual maintenance at 20°C is changed to see the effects at the 10th year-end.

scenario	Cooling scenario B		
barrel layer	SCT B3		
quantity	Vd	I	power density
model	Hamburg	Harper	Hamburg
unit	[V]	[mA]	[uW/mm²]
0 days	109.5	1.62	47.8
2	102.6	1.49	45.5
9	113.0	1.32	44.4
16	129.4	1.24	44.9
23	145.9	1.19	45.8
30	162.2	1.15	46.8
37	178.4	1.11	47.9
44	194.5	1.08	48.9
51	210.4	1.05	50.0
58	226.1	1.02	51.0
65	241.7	0.99	52.1
72	257.2	0.97	53.0
79 days	272.5	0.95	54.0

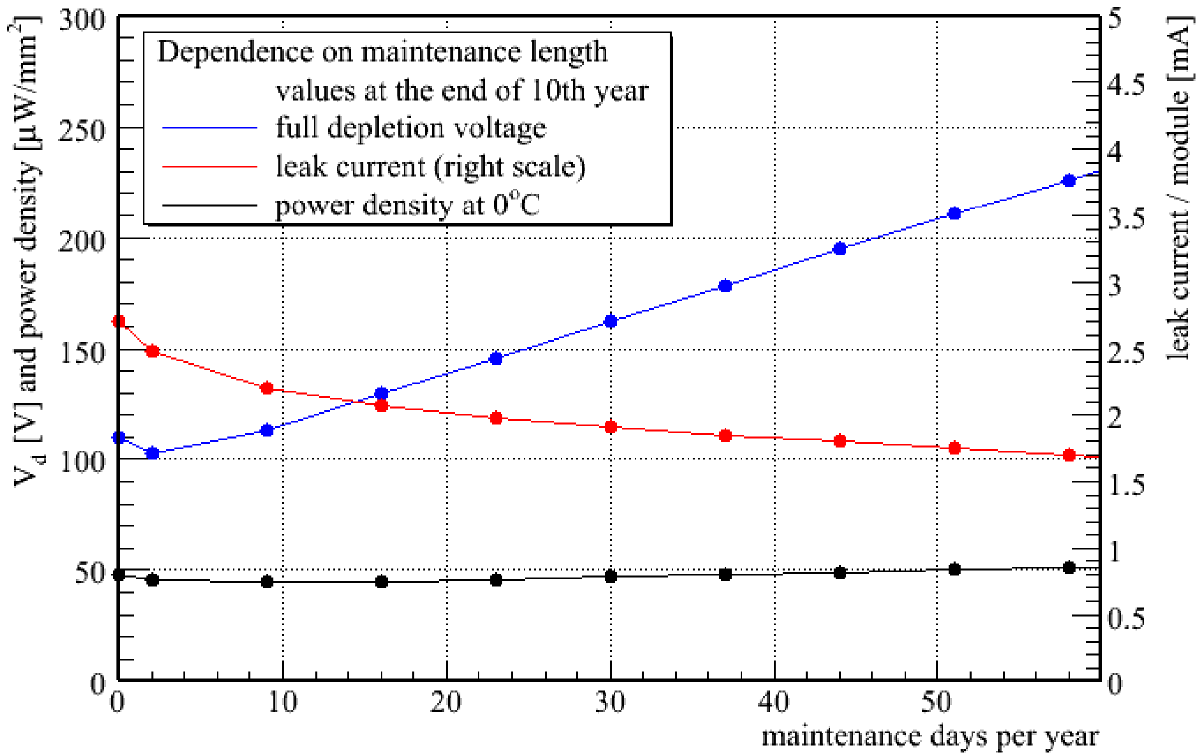


Fig. 19 : Dependence of end-of-10th-year values on the maintenance days at 20°C.

Effect of shutdown with SCT warm-up days

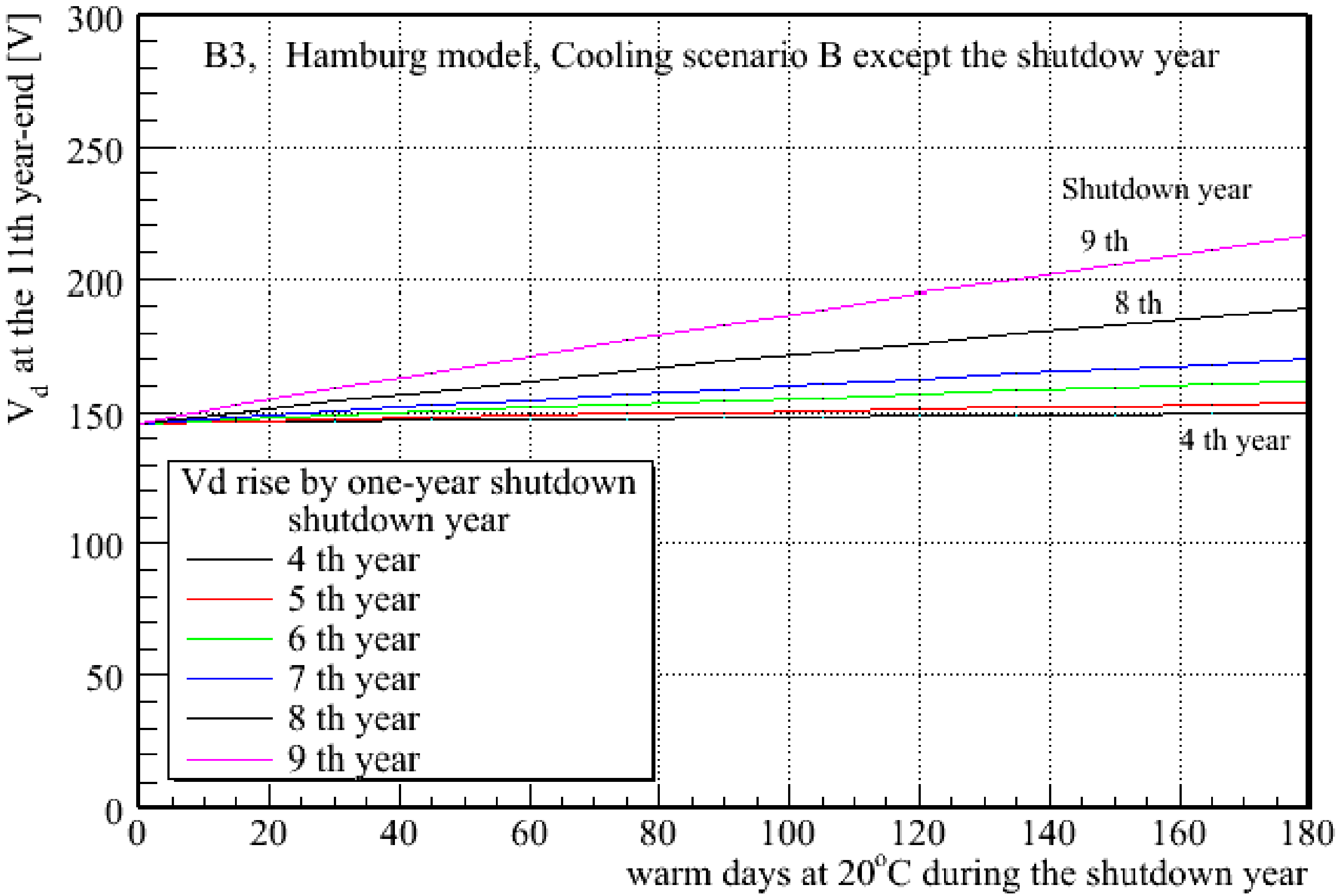


Fig. 20 : One full-year shutdown is inserted at n-th year, during which the SCT is kept at -22°C except warm-up days at 20°C. The luminosity profile is kept same (except one year delay after the shutdown year).

[12] Barrel-6 with special cooling scenario-J

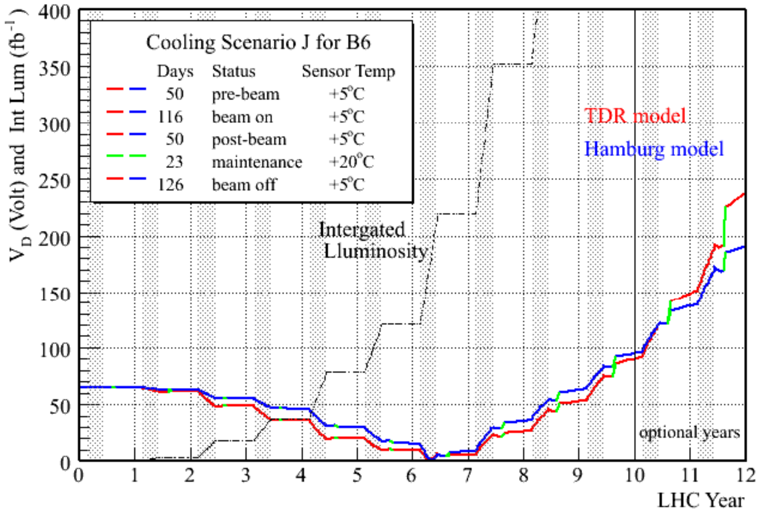


Fig.21: Full depletion voltage V_d

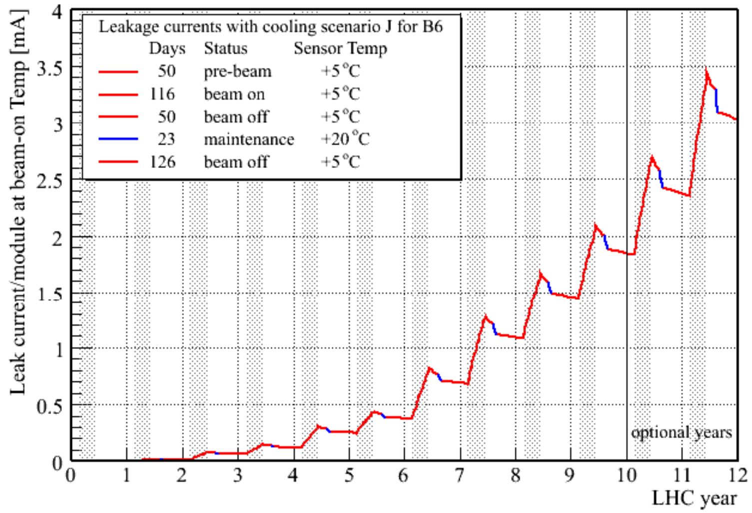


Fig.22: Leakage current / module

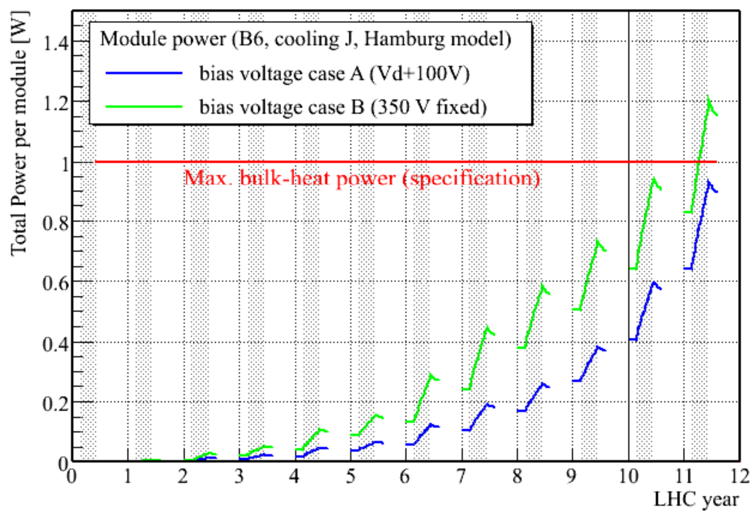


Fig.23: Total bulk heat generation

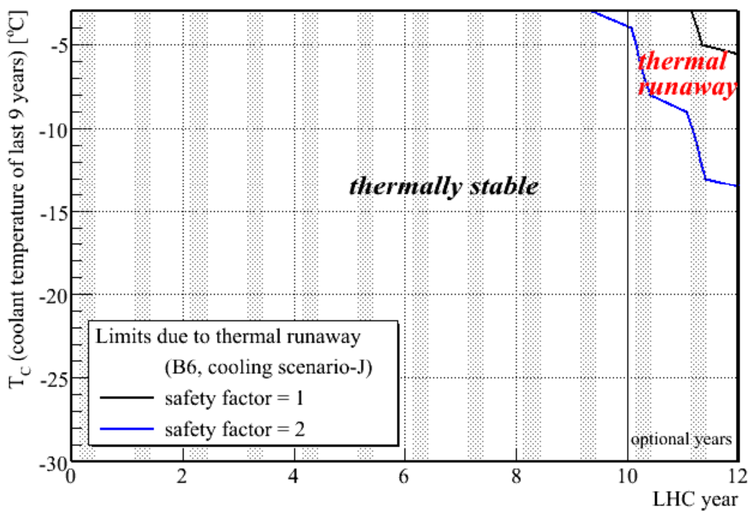


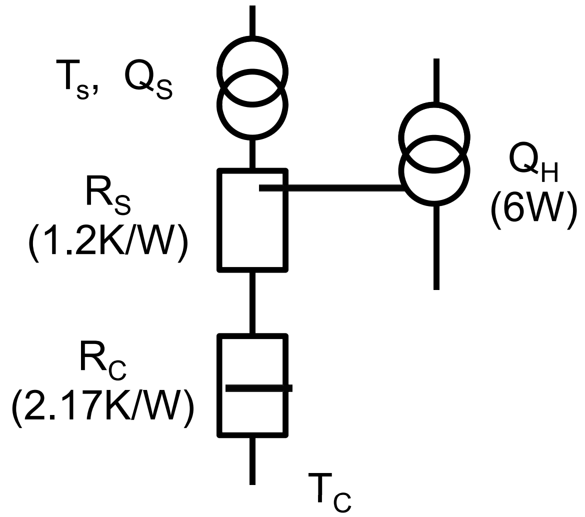
Fig.24: Limit of thermal runaway vs Tc

Note: The maximum voltage is set at 350 V for B6.

[13] Calculation with constant coolant temperature T_C

- So far, the constant sensor temperature is assumed. But this is not true especially for later years. More realistic simulation is to assume the constant coolant temperature.

- As pointed by G. Beck and G. Viehhauser, there are two main thermal resistances to be considered in the new simulation.



	$T_{coolant}$ (°C) for 1st 3 years					$T_{coolant}$ (°C) for next 9 years				
SCT	on	on	on	maintenance	on	on	on	on	maintenance	on
Beam	off	on	off		off	off	on	off		off
days	50	116	50	23	126	50	116	50	23	126
B_C	-15	-15	-15	+20	-15	-22	-22	-22	+20	-22
D_C	0	0	0	+20	0	-22	-22	-22	+20	-22
G_C	-15	-15	-15	+20	-15	-25	-25	-25	+20	-25
I_C	-15	-15	-15	+20	-15	-15	-15	-15	+20	-15

T_{sensor} evolution with constant coolant temperature scenarios

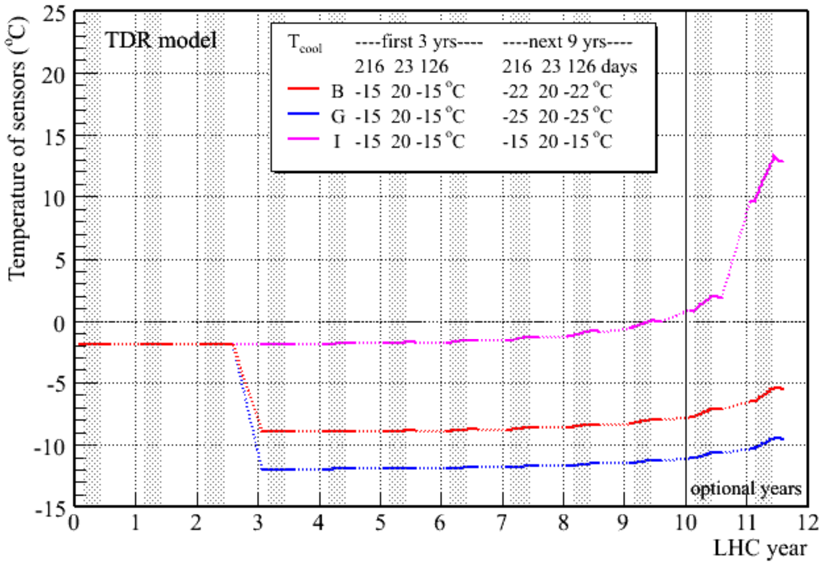


Fig.25 : Sensor Temperature (TDR model)

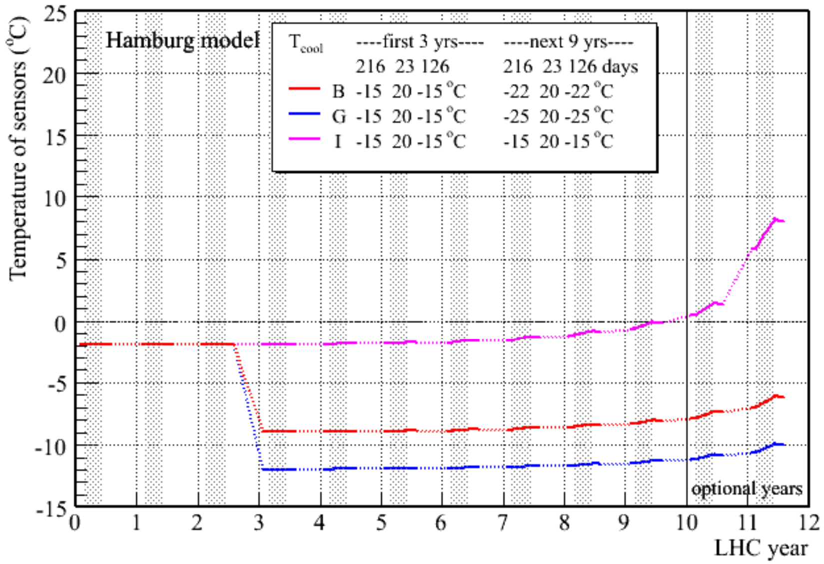


Fig.26 : Sensor Temperature (Hamburg model)

Note that there are no built-in safety factors in these simulations.

The results on thermal runaway points are similar to those obtained by simulation with constant sensor temperature scenarios.

Back up slides

Programmes and summary file can be pick up at

http://atlas.kek.jp/si-soft/Vd/index.html