



MBW-MQW in the LHC

Considerations on expected life and available options

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VSC: E. Page, N. Zelko

Magnetic Measurement team: M. Buzio



Summary

- The magnets, their circuits, the spares, the failure modes
- The dose estimation
- Magnet radiation resistance estimation
- Protective actions
- Improving knowledge and possible development
- Considerations on interventions in point 7 and general remarks
- Documents
 - ECR LHC-MW-EC-0001: approved referring to LS1 all implementation completed
 - ECR LHC-MW-EC-0002: approved referring to LS2 pending final validation on ABP, collimation simulations and requiring design of absorber from the collimation team

THE MAGNETS, THEIR CIRCUITS, THE SPARES, THE FAILURE MODES



The magnets



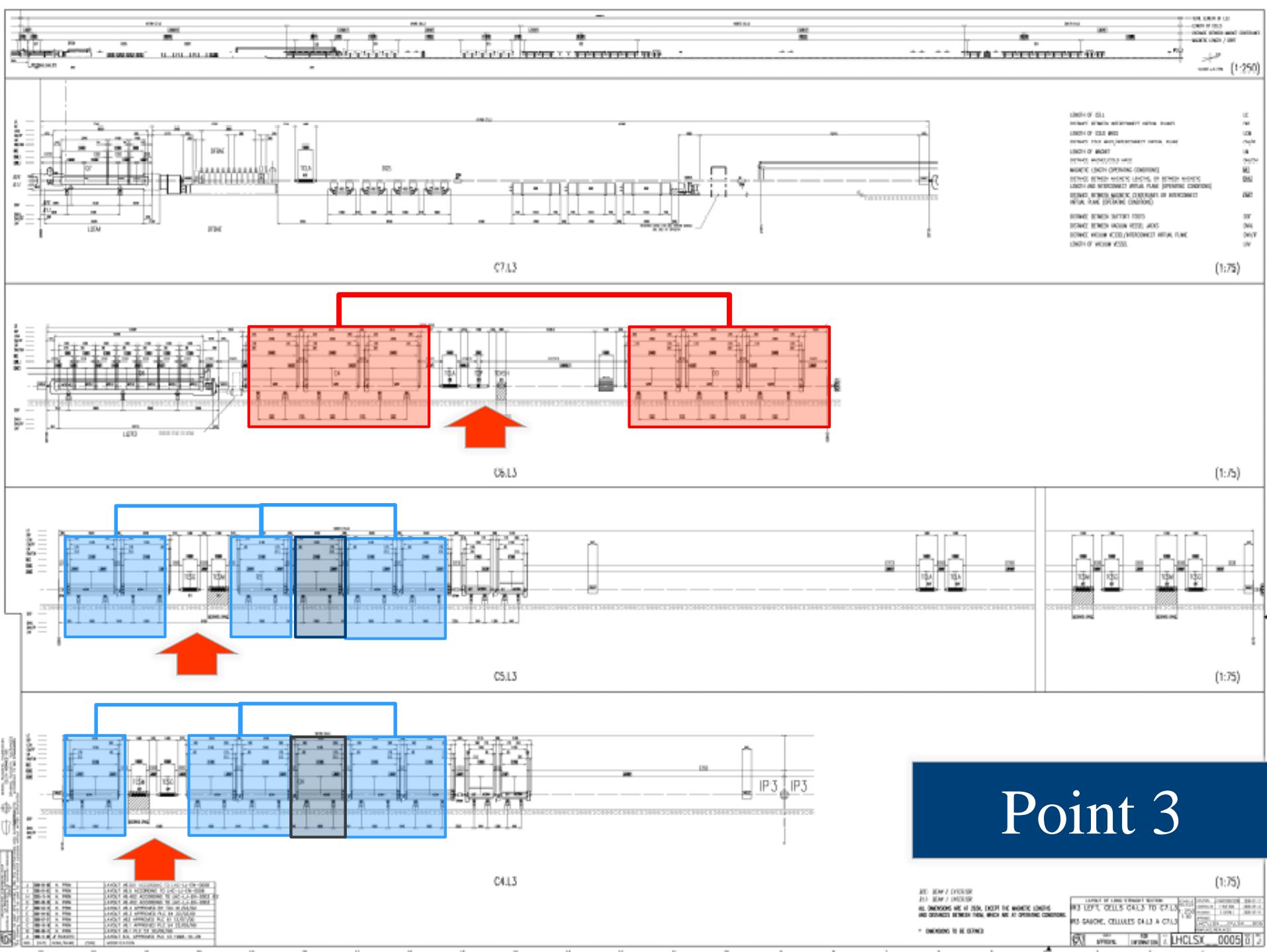
MQW

- Produced by Alstom-Canada
- Welded and bolted yoke
- 48 units in LHC IR3 and IR7
- 4 spares available

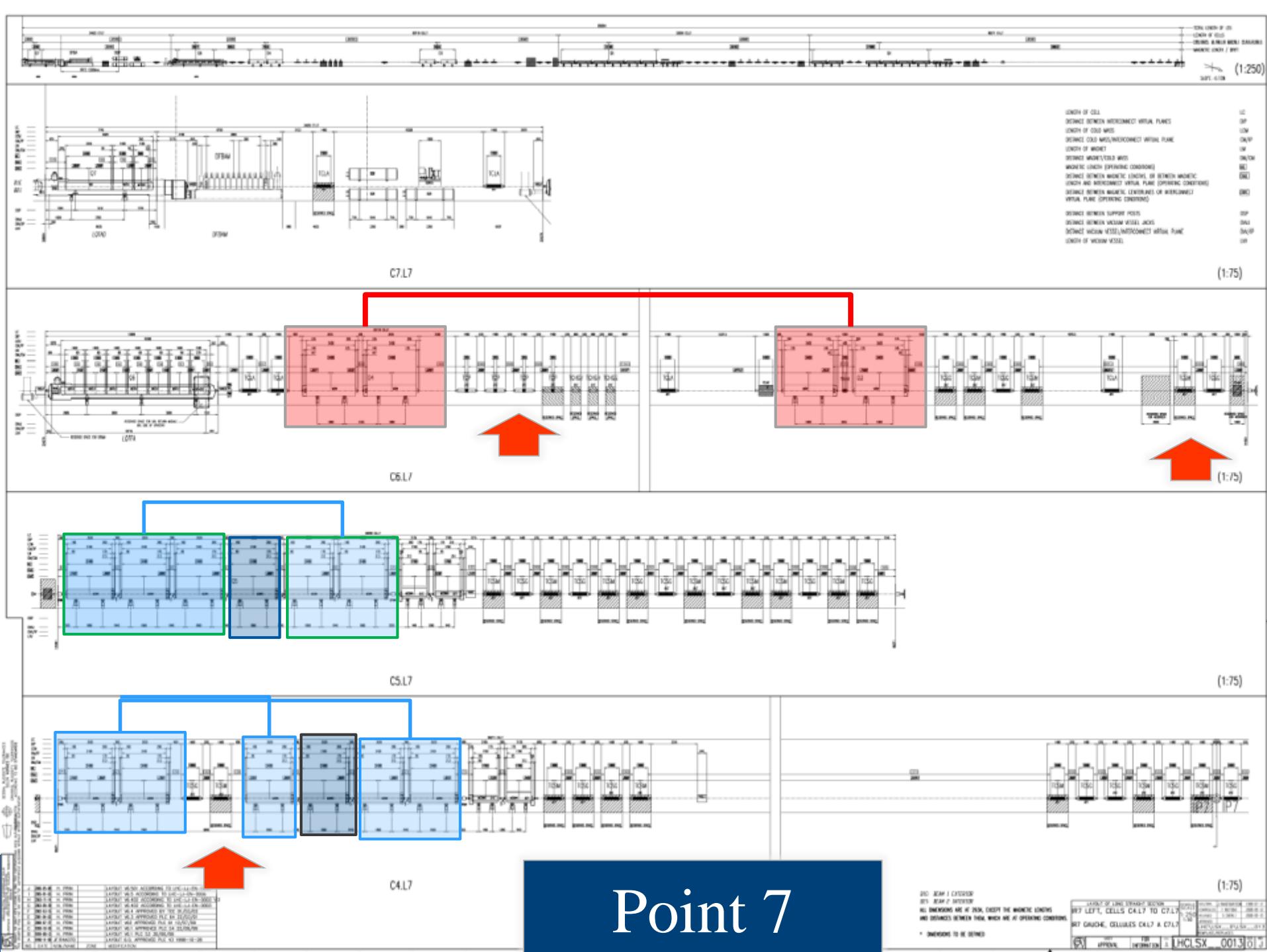


MBW

- Produced by BINP
- Welded and bolted yoke
- 20 units in LHC IR3 and IR7
- 3 spares available + 1 spare for the life test



Point 3



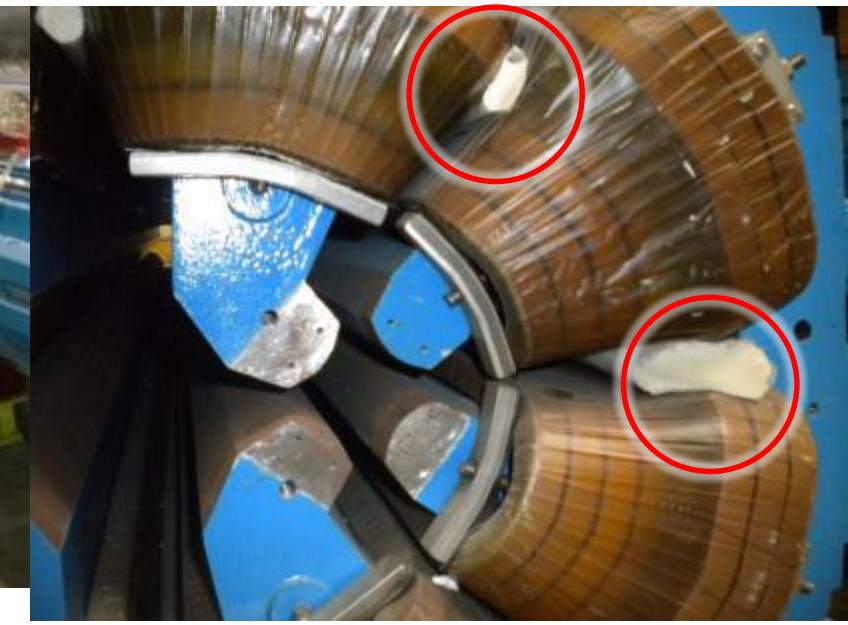
Point 7

MQW point 7 and 3

MBW point 7 and 3

Characteristics	RD34.LR7	RD34.LR3
I ultimate [A] (layout database)	810	810
Voltage I ultimate [V]	440	700
I 7 TeV (Fidel report)	643	643
Voltage I 7 TeV	350	556
Number magnet in series in circuit	8	12
Turn/magnet		84
Estimated ultimate inter-turn voltage [V]	0.65	0.7
Estimated inter-turn voltage 7 TeV [V]	0.52	0.55
Estimated ultimate inter layer voltage [V]	9.2	9.7
Estimated inter layer voltage 7 TeV [V]	7.2	7.8
Circuit energy ultimate [Kj]	472	793
Circuit energy 7 TeV [Kj]	297	500
Insulation inter turn [mm]	$2X(2X0.15)=0.6$ glass tape	
Insulation inter layer [mm]	$2X(2X0.15)+2X(2X0.15)+1(\text{glass cloth}) =1.6$ glass tape	
Ground insulation	$2X(2X0.15)+(0.15X6)=1.8$ glass tape	
Resin used	EPC-1: resin ED-16 100 Hardener MA 2.28 □ K Plasticizer MGF-9 20 TEa accelerant 0.5	

Identified Failure modes

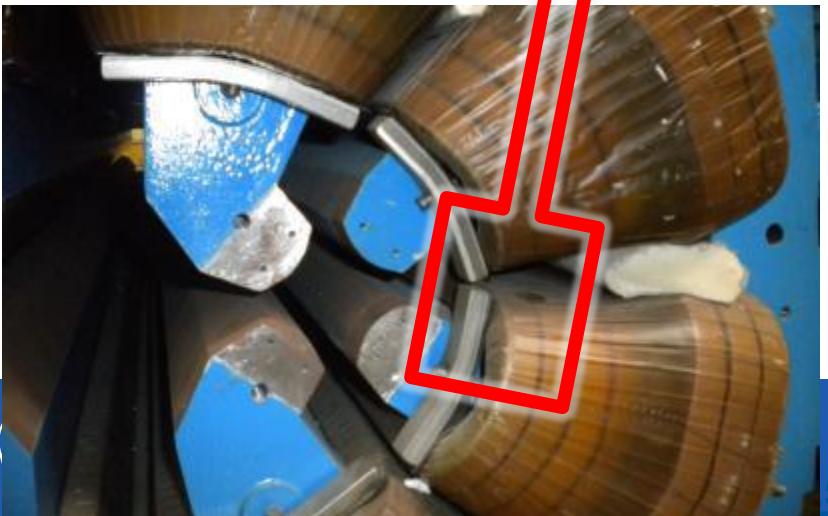
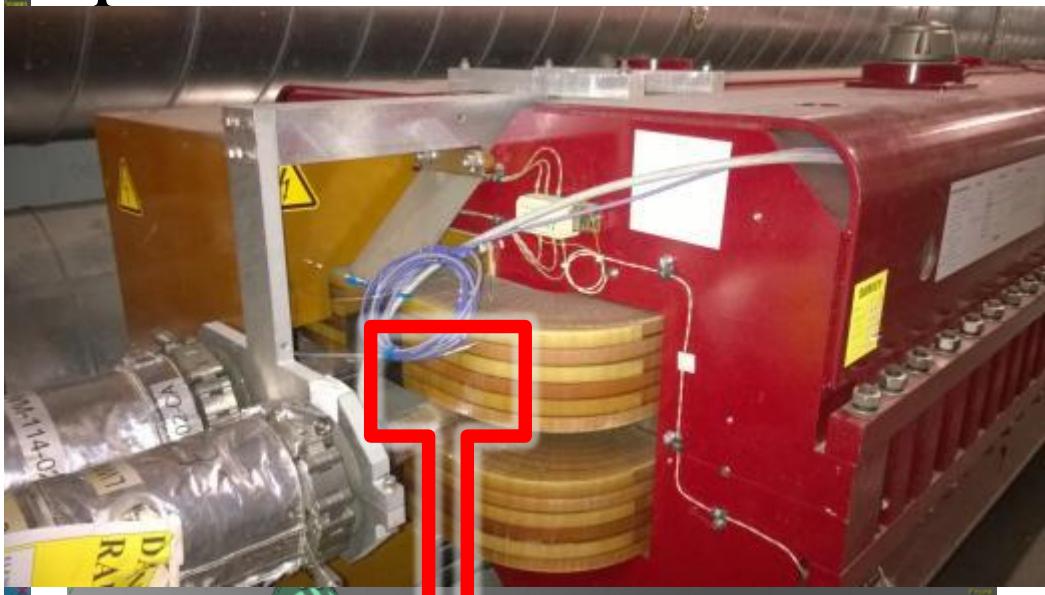
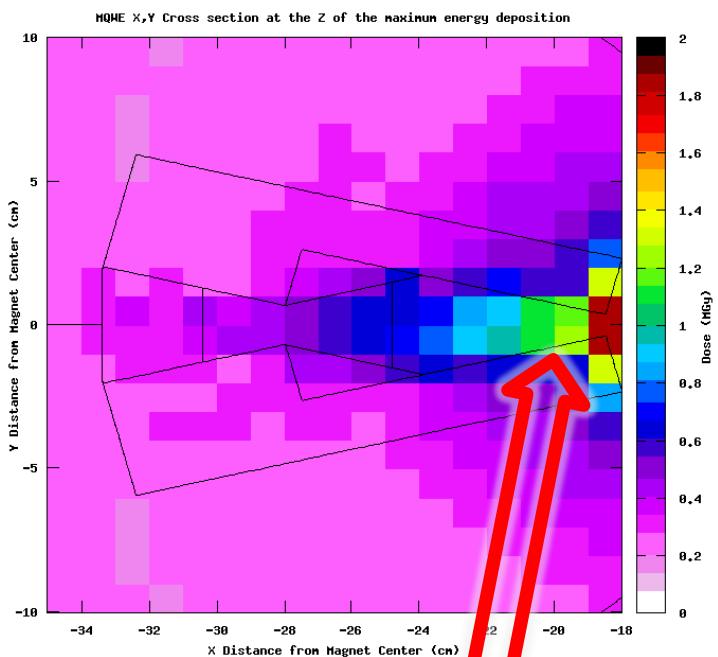


- Degradation of the insulation system due to radiation leading to inter turn short or shorts to ground
- Degradation of the mechanical shimming performed with ambient temperature cured resins

- Degradation of the insulation system due to radiation leading to inter turn short or shorts to ground
- Remark magnet build with no coil on the mid plane and therefore out from the expected zone of highest losses

DOSE ESTIMATION

nap



$1.15 \times 10^{-1} \mu\text{m}^2/\text{sr}$ (50-55 GeV).
5 TeV relaxed collimator settings

Relationship dose vs. luminosity and point 7 vs. point 3

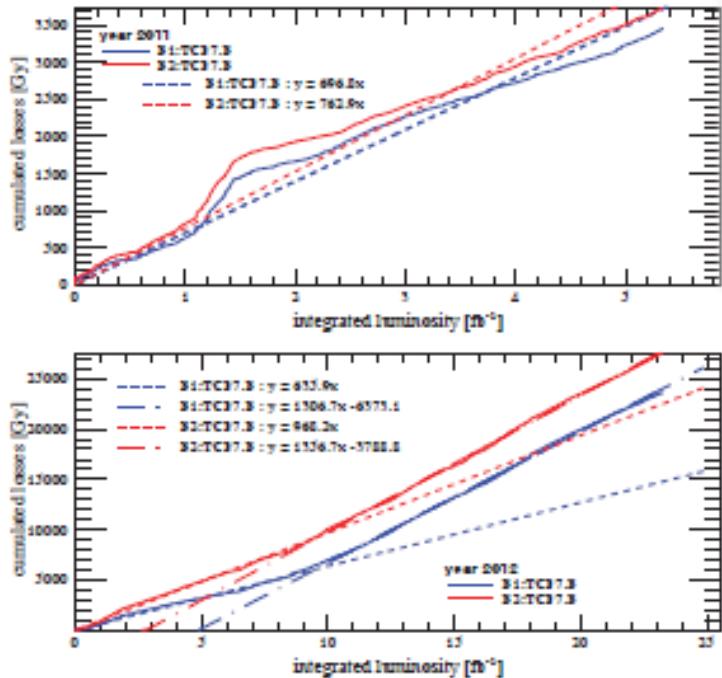


Figure 2: Cumulated losses at the BLM located downstream the primary skew collimator in IR7 during 2011 (top) and 2012 (bottom) as a function of the LHC delivered integrated luminosity to ATLAS.

It was recently suggested that this increase in slope is probably linked to the different sensitivity of the BLM_TCP.C that provides twice (1.8) the signal for vertical losses than for horizontal. A change in distribution between the horizontal and the vertical plane (with the same total losses) would explain the change in slope without meaning increased loss on the magnet. Factor 2 therefore probably conservative

2

Table 2: Result from the linear fit to the cumulated losses during each fill in 2011 and 2012 as a function of the LHC delivered integrated luminosity to ATLAS.

	Fit results (slope) [Gy fb]	IR7		IR3	
		B1	B2	B1	B2
2011	696.8		762.9	196.7	115.1
2012 before TS2	635.9		968.2	26.8	12.6
2012 after TS2	1306.7		1356.7	54.7	30.1

Worst P3 $196.7/(697+196.7)=0.23$

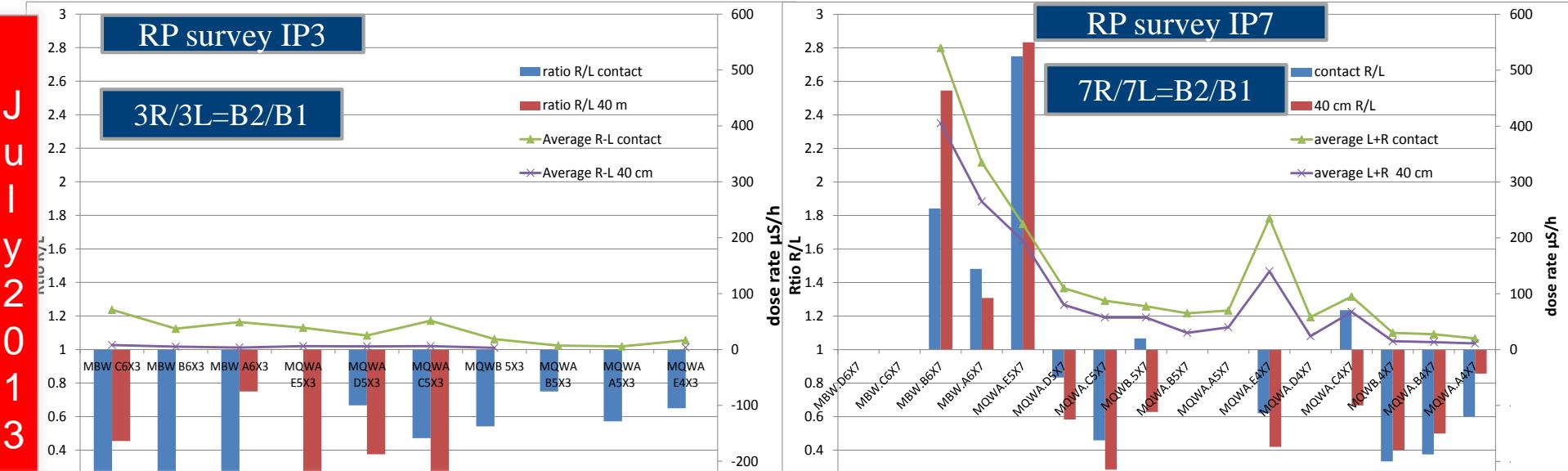
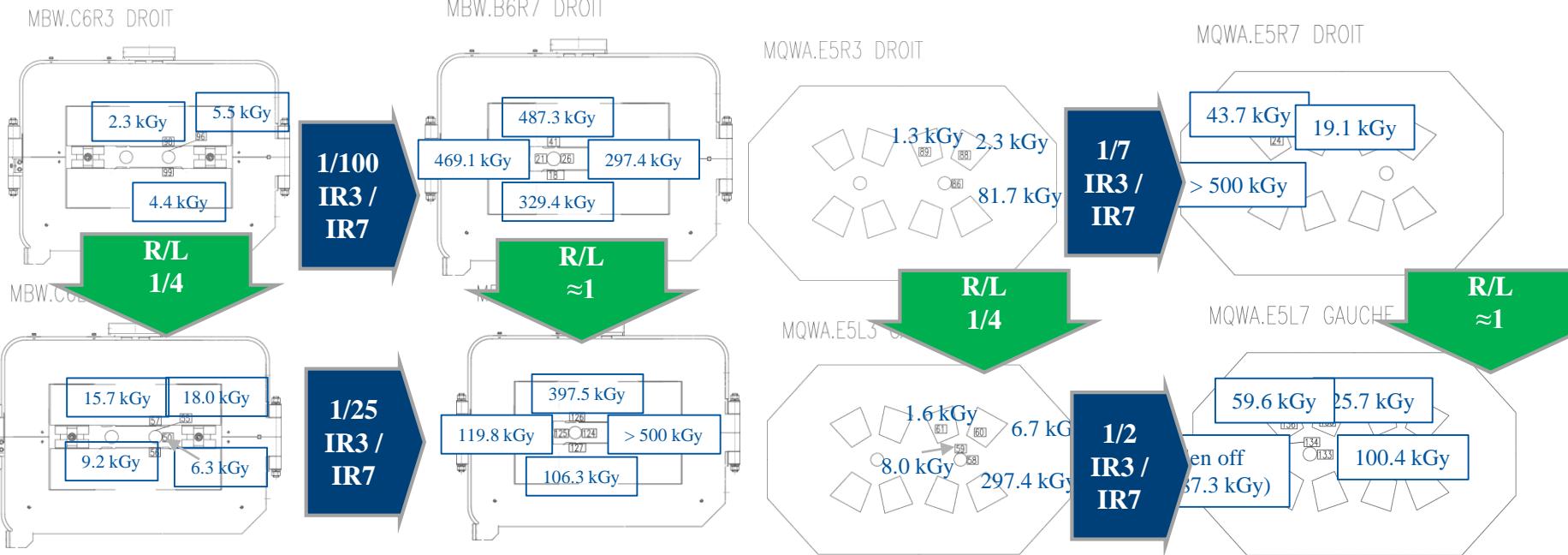
Worst P1357 $1357/(1357+30)=0.97$

ESTIMATE OF WARM MAGNETS LIFETIME IN THE BETATRON AND MOMENTUM CLEANING INSERTIONS OF THE LHC

Analysis exp. data point 3 and point 7

T
S
2
0
1
2

J
U
I
Y
2
0
1
3



Data from RP survey courtesy of A. Herve and C. Tromel. Data of dosimeter courtesy of DGS-RP High dosimetry

Dose evaluation process for each point

IP 3

1

$150 \text{ fb}^{-1} \rightarrow 3$
 $350 \text{ fb}^{-1} \rightarrow 7$
 $3000 \text{ fb}^{-1} \rightarrow 60$

2

0.23

L=1
R=0.5

Fluka model results with 1.15×10^{16} p lost **per interaction point** E 7 TeV.

Scale to the dosimeter readings as benchmark (TS2) in particular for 7 L

Scale to the LS1, LS2 LS3 and HL-LHC integrated luminosity

Scale to the increase slope dose/luminosity after TS2

Normalise to a total losses (adding the 2 points) of 1.15×10^{16}

IP 7

1

$150 \text{ fb}^{-1} \rightarrow 3$
 $350 \text{ fb}^{-1} \rightarrow 7$
 $3000 \text{ fb}^{-1} \rightarrow 60$

2

0.98->1

L=1
R= (0.4->2)

Scale to the Left and Right using RP survey



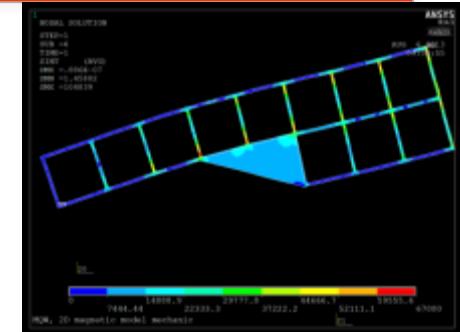
MAGNET RADIATION RESISTANCE ESTIMATION

Radiation resistance dose estimation

Degradation of mechanical properties appears and it can be measured before degradation of electrical properties

Actions of the fillers
on the radiation
resistance

Results mechanical test
of the irradiated used
resin or **similar** one



Resin	Hardener	Additives	Filler	Composition (g/g)	Fig	Dose for 50% flex. (Mrad)	Dose Range (Mrad)
DGEBA	1,1-BB		Pigment	100-27-200	5-14	1.3	1-2
DGEBA	1,1-BB		Silica	100-27-200	5-14	20	
DGEBA	1,1-BB		Silica	100-27-200	5-18	15-4	
DGEBA	1,1-BB		Silica (5 micron)	100-27-20	5-16	14.8	20-15
DGEBA	1,1-BB		Silica (10 micron)	100-27-20	5-16	14.8	
DGEBA	1,1-BB		Silica (10 micron)	100-27-20	5-18	14.8	
DGEBA	1,1-BB		Silica (10 micron)	100-27-20	5-18	14.6	
DGEBA	1,1-BB		Silica (10 micron)	100-27-200	5-17	12.1	
DGEBA	NBPA	HEMAN	Silicon (Mg-magnesite)	100-40-2-200	5-17	<30	<10
DGEBA	NBPA		Alumina + Silicate of Beryllium	100-27-2-200	5-14	35.0	15
DGEBA	MDI		Magnesite	100-27-120	5-14	38	18
DGEBA	MDI		Graphite	100-27-60	4.6	38.8	25-30
DGEBA	MDI		Graphite	100-27-60	5-18	35.9	
DGEBA	MDI		Alumina	100-27-220	4.7	23.5	
DGEBA	MDI		Alumina	100-27-220	5-14	55.7	20-90
DGEBA	MDI		Alumina	100-27-100	5-15	20.8	
DGEBA	MDI		Alumina	100-27-210	5-15	42.5	
DGEBA	MDI	Fibre de verre	Fibre de verre	100-27-90	5-18	82	88-180
DGEBA	MDI	Fibre de verre	Fibre de verre	100-27-60	5-18	106	>100
BPI	MDI	Fibre de verre	Fibre de verre	100-29-90	5-18	>100	>100
TGME	MDI	Fibre de silice	Fibre de silice	100-41-50	5-28	>100	>100
TGME	MDI	Fibre de silice	Fibre de silice	100-49-50	5-28	>100	>100

Estimation of the level of
resistance of the
insulation system to
radiation

Value of
mechanical load
in the insulation

But ...

- 1) What is the effect of the insulation thickness on the degradation ?
- 2) We know that exposure to air during irradiation should make the larger the damage.
How much ?
- 1) Worth re-evaluating the correlation between electrical and mechanical properties degradation

Applying the above mentioned methodology

MQW

MBW

Coil insulation

EPN1138 42%+ GY 6004 42% + CY 221 16% + HY 905 100 %+ 30ml DY 073+ glass fibre

Level for pure resin
 $10 \rightarrow 20$ MGy

Level for charged resin
 $20 \rightarrow 50$ MGy

Limit of damage
 >50 MGy

Coil to Coil spacer

EPON 826 + RP 1500 + silica particle filler

Level for pure resin
 $5 \rightarrow 10$ MGy

Level for charged resin
 $10 \rightarrow 20$ MGy

Limit of damage
 >20 MGy

Coil insulation

EPC-1: resin ED-16 100 Hardener MA 2.28 + K Plasticizer MGF-9 20+ TEa accelerator 0.5 + glass fibre

Level for pure resin
 $40 \rightarrow 60$ MGy

Level for charged resin
 $60 \rightarrow 80$ MGy

Limit of damage
 >80 MGy

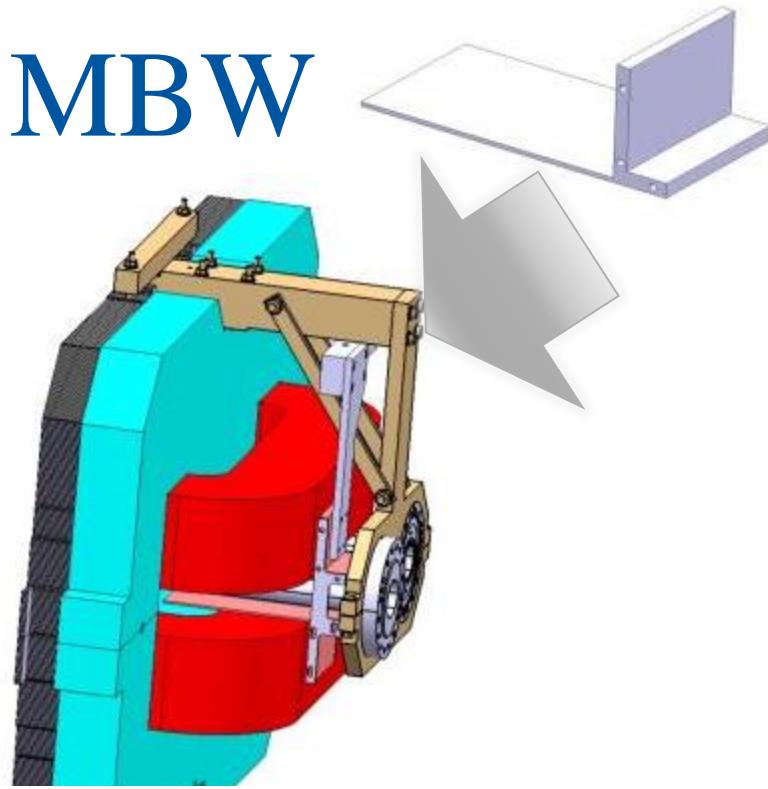
	Dose [MGy] for integrated luminosity 150 fb^-1		Dose [MGy] for integrated luminosity 350 fb^-1		Dose [MGy] for integrated luminosity 3000 fb^-1	
	R	L	R	L	R	L
MQWA.A4	0	0	0	0	2	4
MQWA.B4	0	0	0	0	2	4
MQWB.4	0	0	0	1	2	4
MQWA.C4	0	0	0	1	3	6
MQWA.D4	0	1	1	2	7	14
MQWA.E4	2	3	4	8	35	69
MQWA.A5	1	2	3	5	22	44
MQWA.B5	1	3	3	6	28	55
MQWB.5	3	7	8	15	66	132
MQWA.C5	8	15	18	36	155	309
MQWA.D5	2	4	4	9	37	75
MQWA.E5	3	7	8	16	69	138
MBW.A6	2	4	5	9	40	79
MBW.B6	2	5	5	11	46	92
MBW.C6	3	7	8	15	65	130

Point 3 and 7 coil
magnet damage
estimation

	Dose [MGy] for integrated luminosity 150 fb^-1		Dose [MGy] for integrated luminosity 350 fb^-1		Dose [MGy] for integrated luminosity 3000 fb^-1	
	R	L	R	L	R	L
MQW	MBW		MQWA.A4	1	1	10
From 10 to 20 MGy	From 40 to 60 MGy		MQWA.B4	0	1	9
From 20 to 50 MGy	From 60 to 80 Mgy		MQWB.4	1	2	17
Larger than 50 MGy	Larger than 80 MGy		MQWA.C4	6	6	123
			MQWA.D4	4	4	74
			MQWA.E4	7	14	136
			MQWA.A5	3	3	56
			MQWA.B5	4	4	86
			MQWB.5	4	4	86
			MQWA.C5	2	5	40
			MQWA.D5	5	7	95
			MQWA.E5	41	14	815
			MBW.A6	22	16	450
			MBW.B6	37	19	741
						15
						22
						43
						123
						74
						272
						56
						86
						86
						99
						136
						370
						321
						370

PROTECTIVE ACTIONS

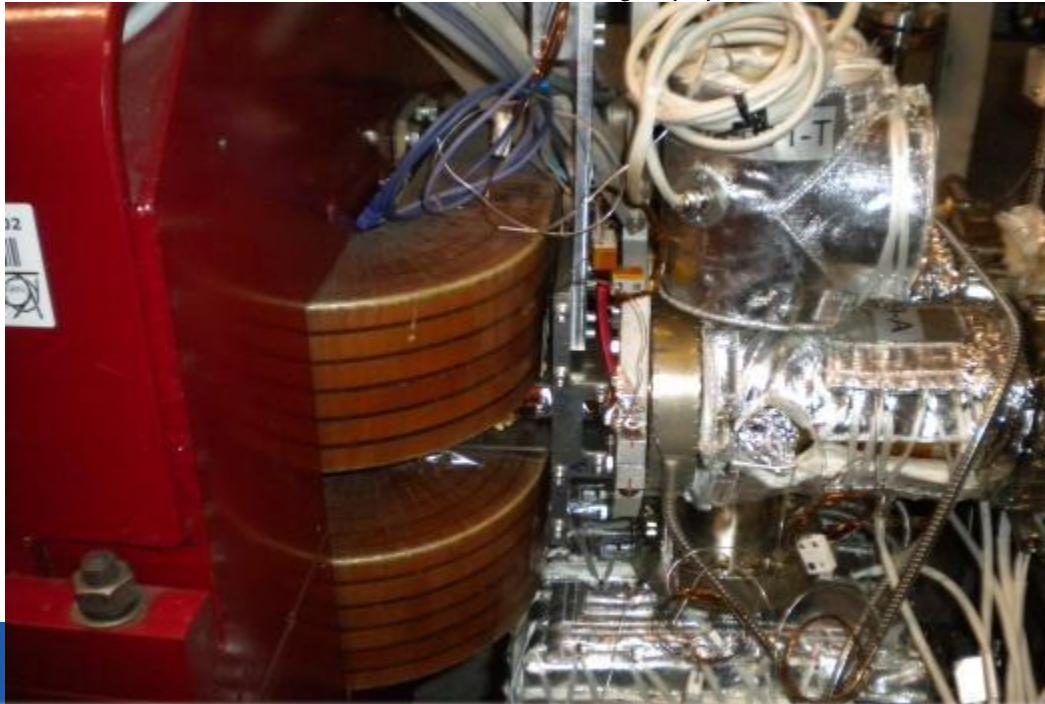
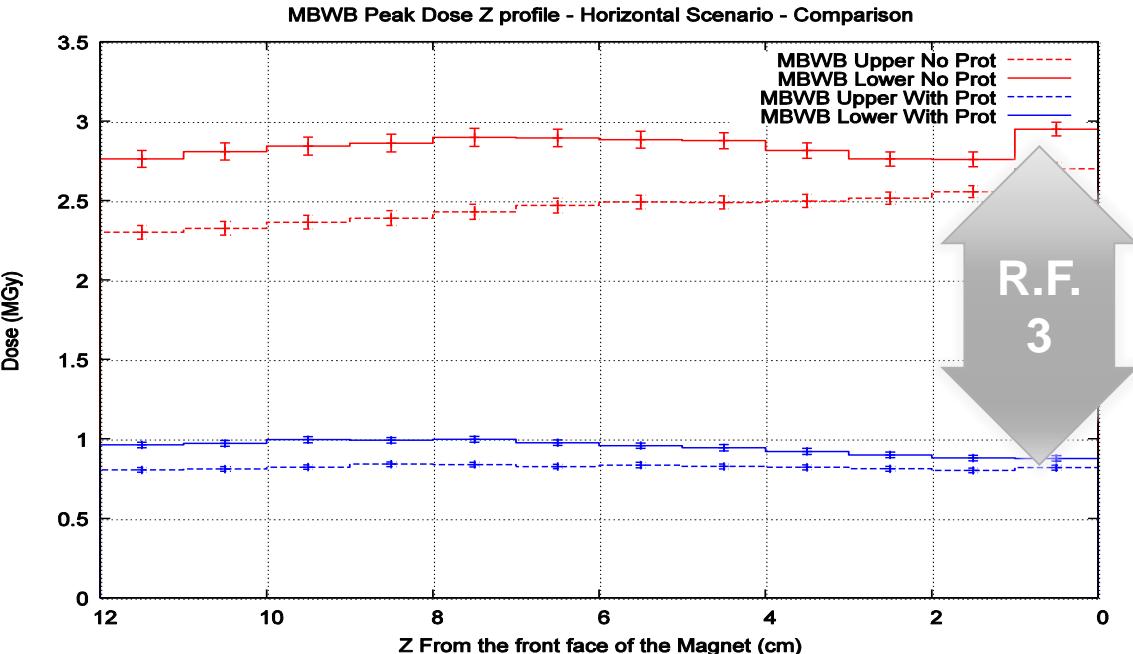
MBW



- For max effectiveness we have to target the higher possible density candidate therefore W, or better the alloys for machining

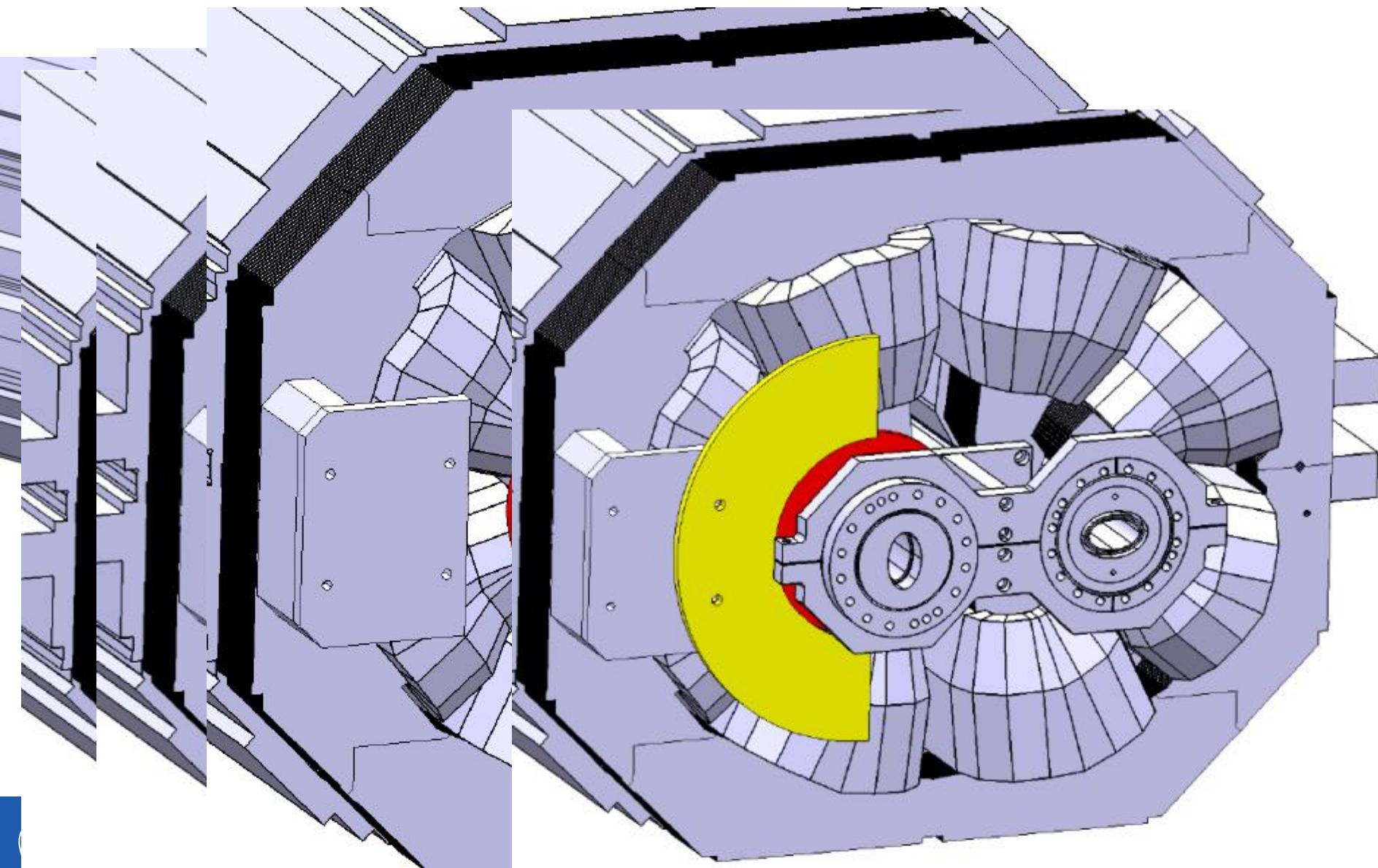
	Inermet IT180
Nominal density	18
W content %	95
Balance	Ni,Cu
E-modulus	360 GPa

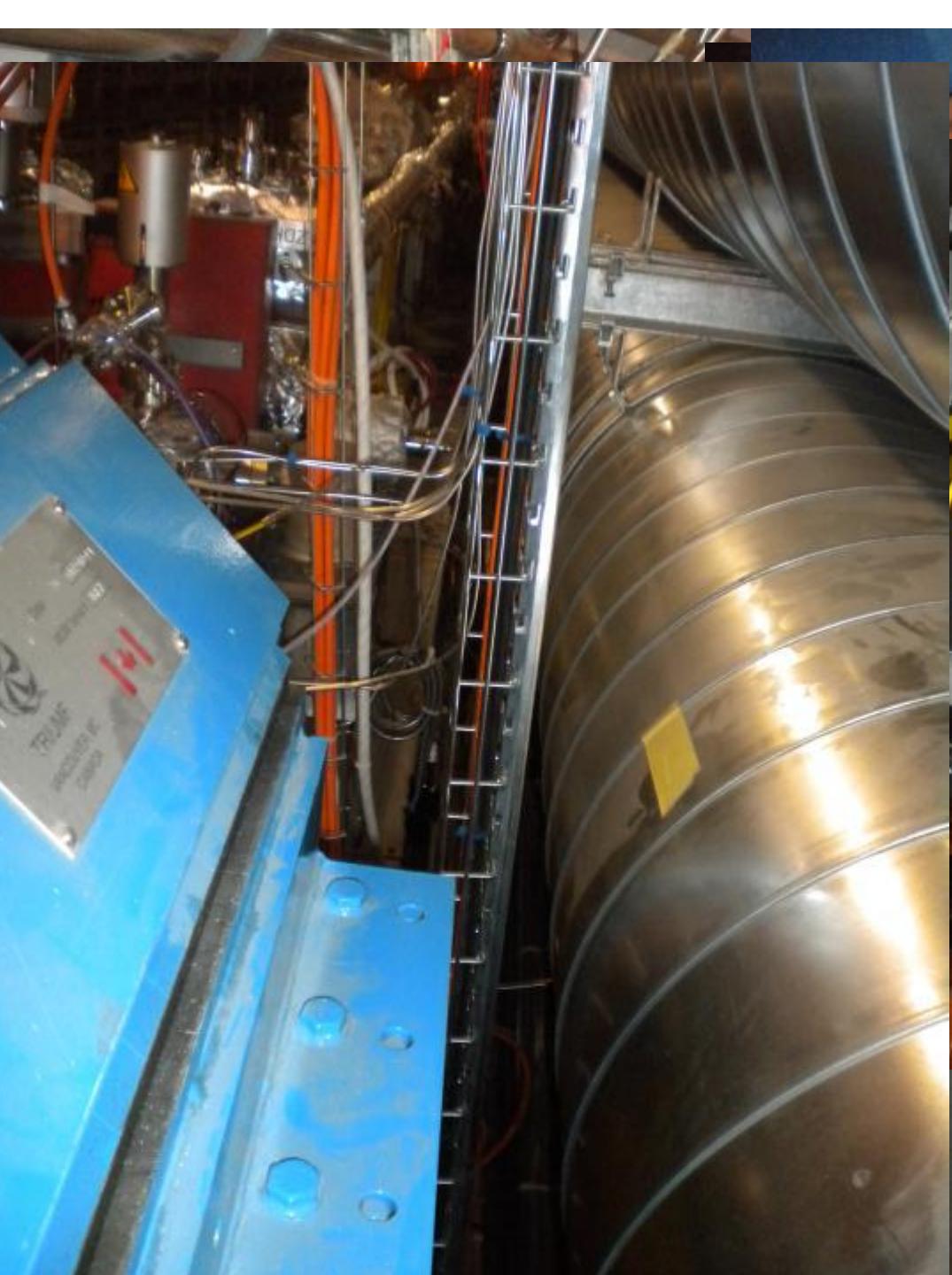
- Material staging along the MQW magnet length under study



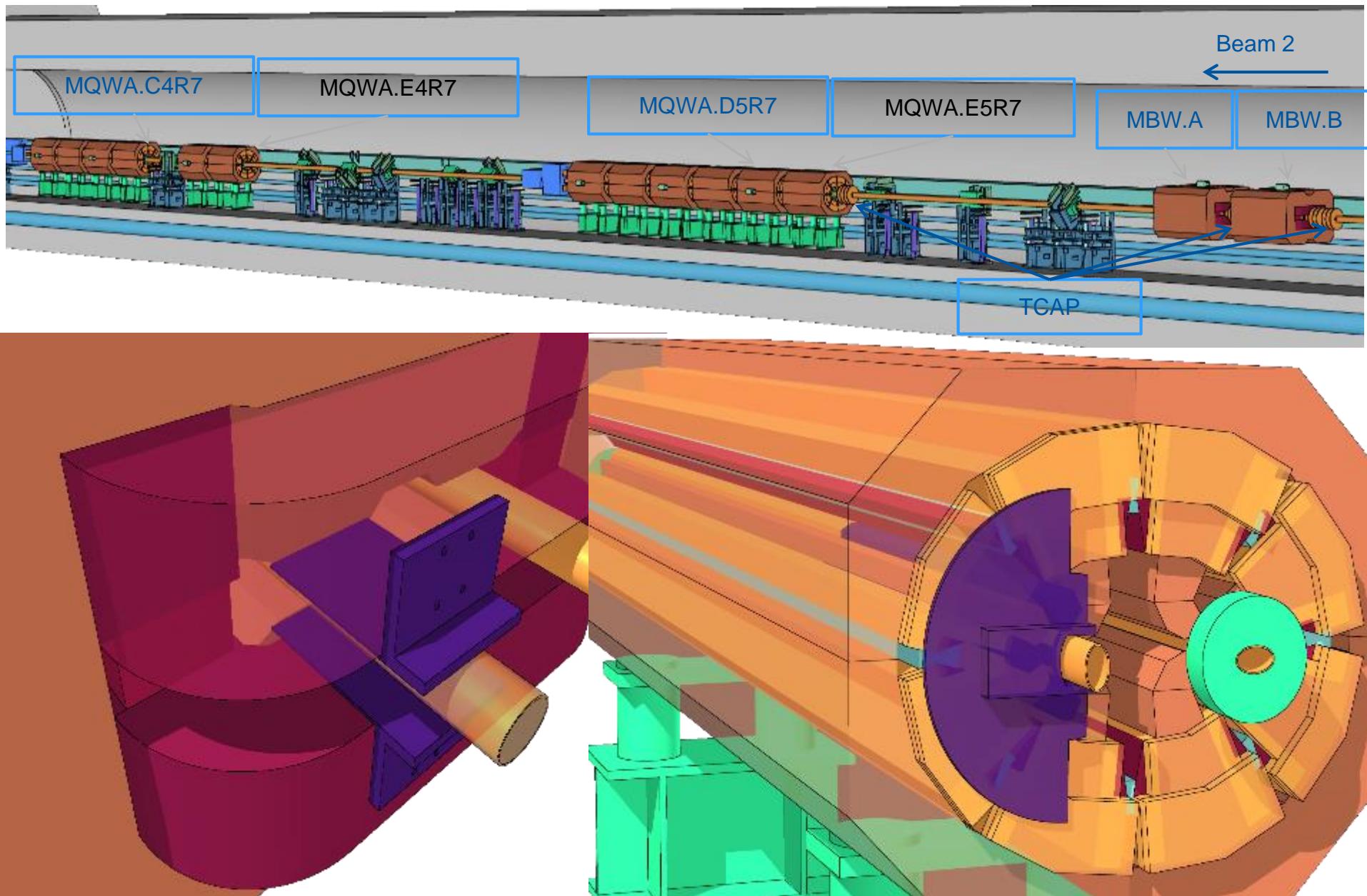
All Fluka computations courtesy of E. Skordis

MQW





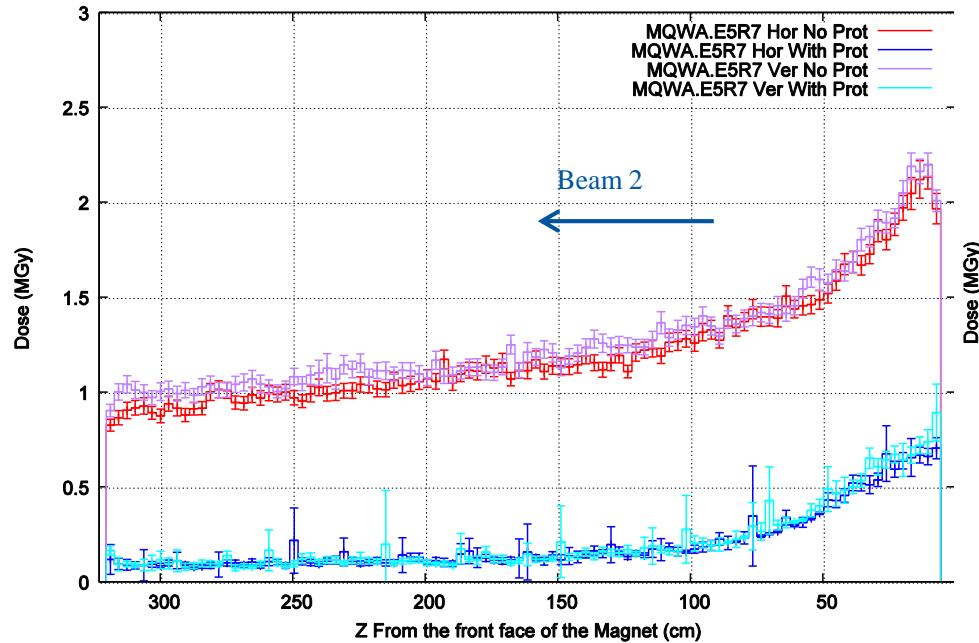
MBWA - MBWB Peak Dose profile



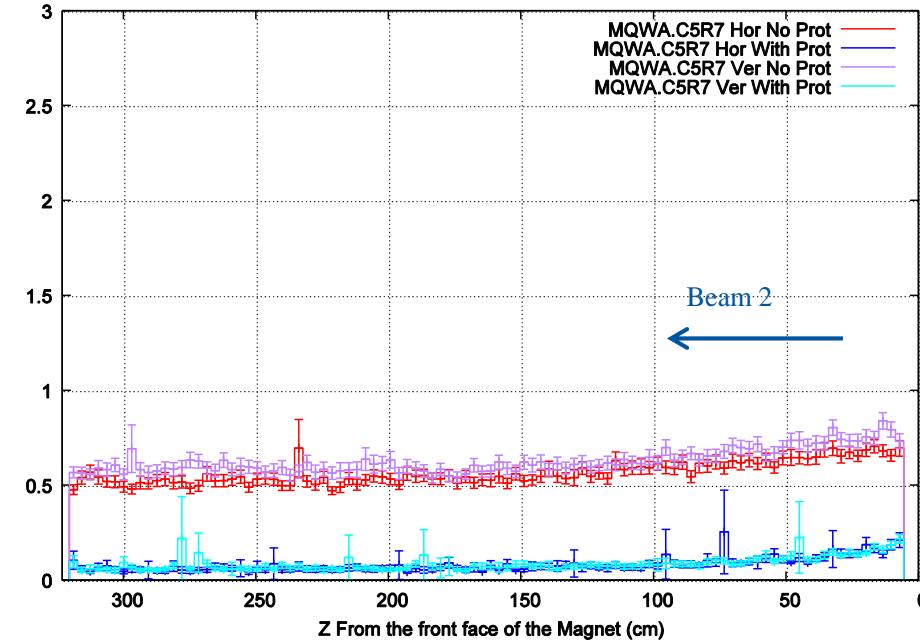
MQW shielding effect on the coil

Normalization: $1.15 \cdot 10^{16} \text{ p}$ (50 fb^{-1})

MQWA.E5R7 Peak Dose Z profile - Comparison



MQWA.C5R7 Peak Dose Z profile - Comparison

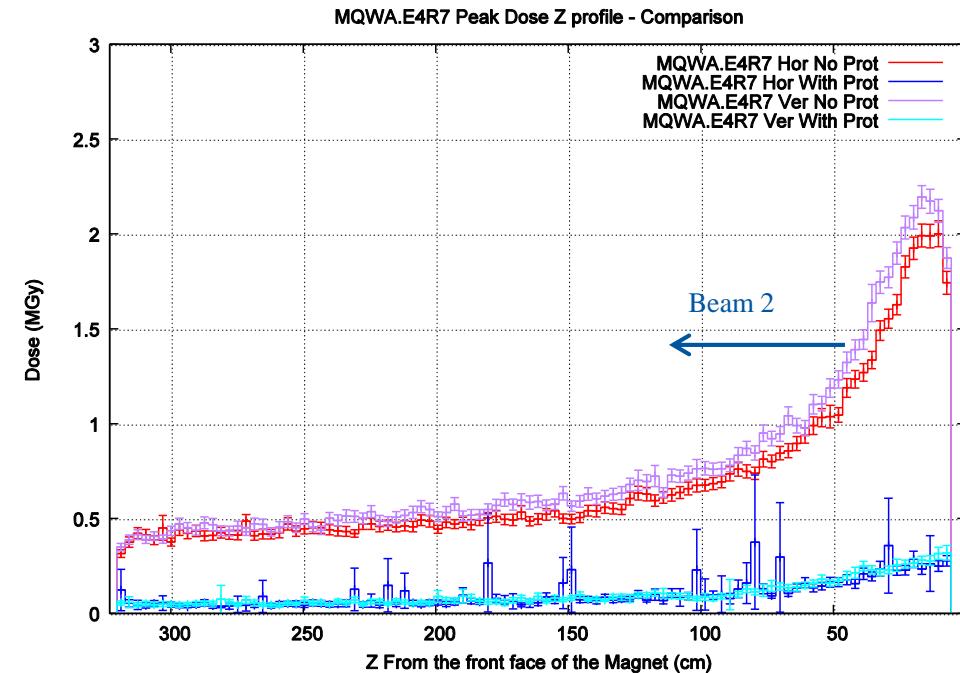
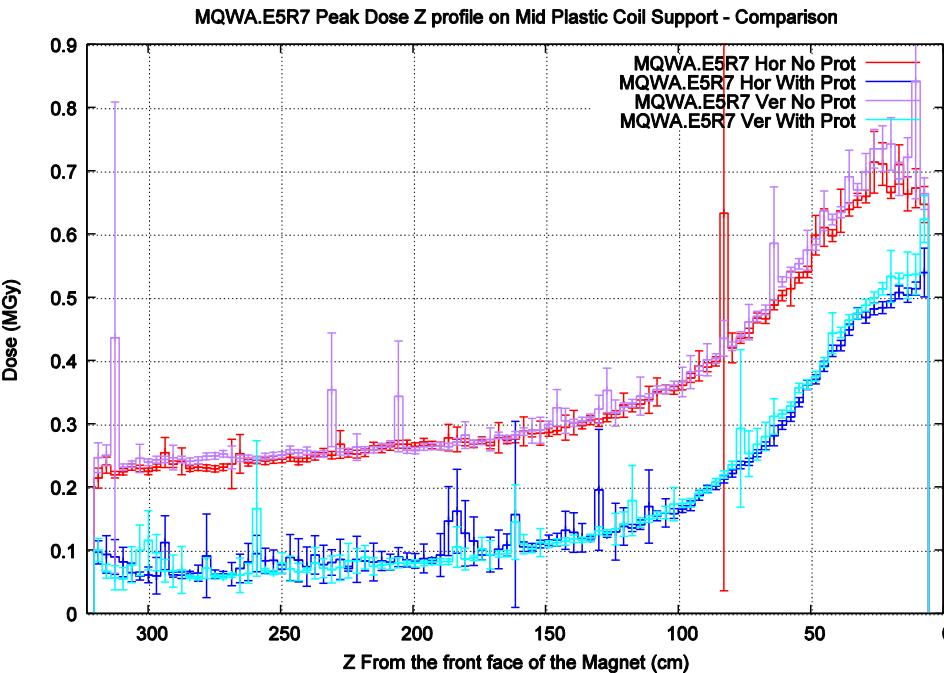


Reduction Factor 3 on most exposed magnet with the hardest spectra. It shadows 20 % the radiation on the following magnet

Reduction Factor 4 on less exposed magnet with the softer spectra.

MQW shielding effect on the coil to coils spacers

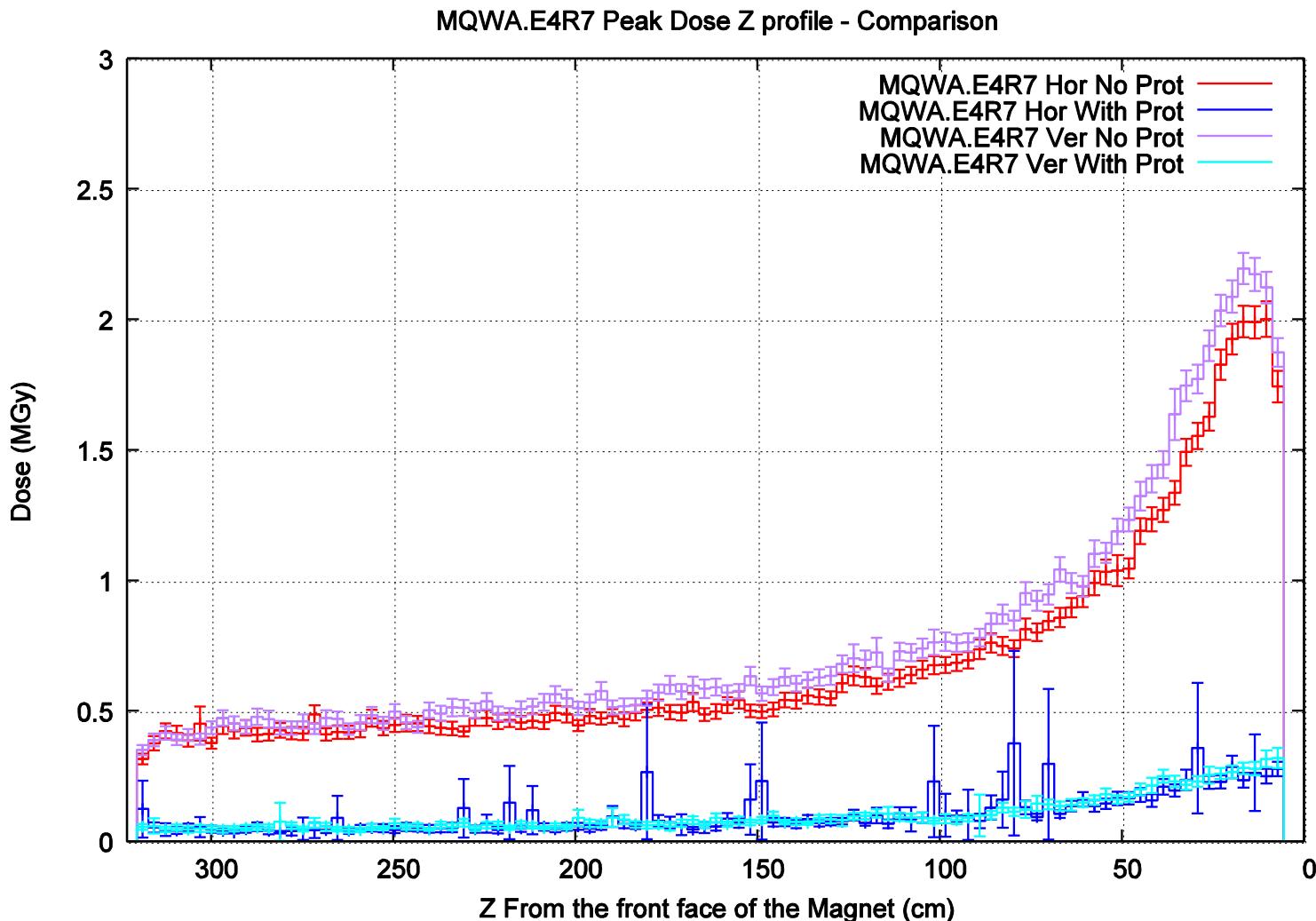
Normalization: $1.15 \cdot 10^{16} \text{ p}$ (50 fb^{-1})



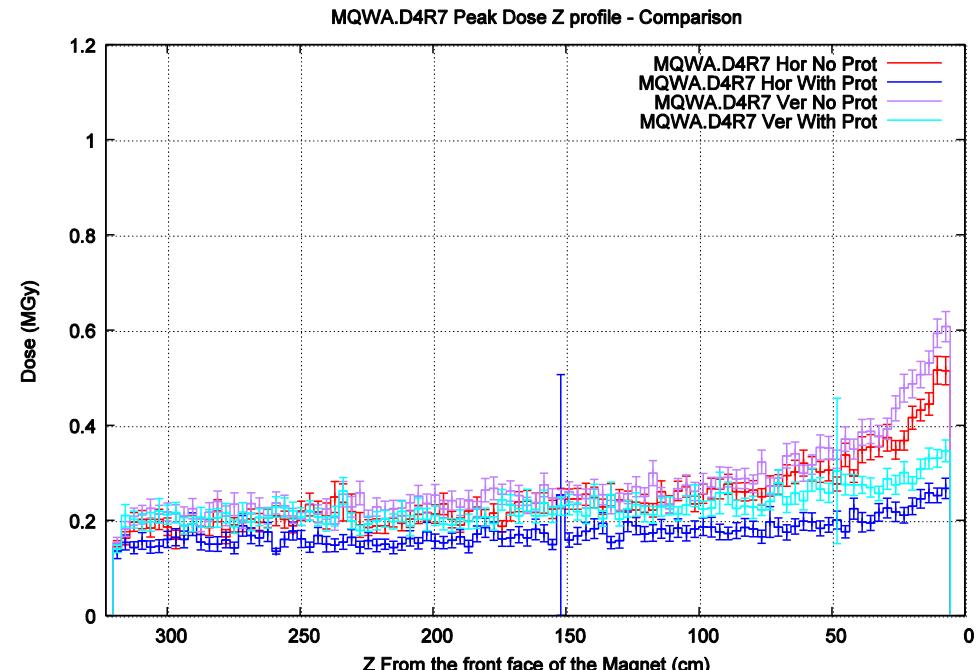
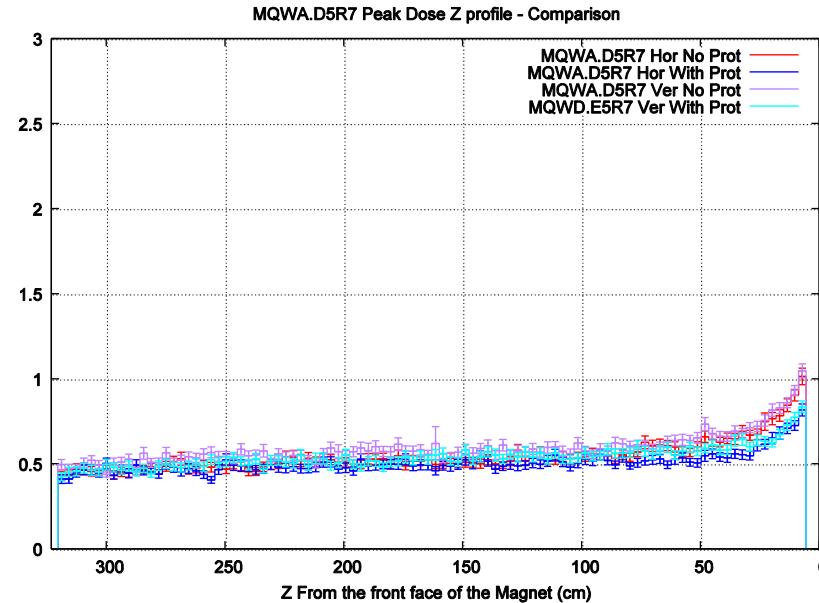
Peak reduced to 70 % of initial value.
Largest part of the magnet benefits of a
reduction to 50% (reduction factor 2) It
shadows 30 % the radiation on the
following magnet

Reduction Factor 5-6 on less exposed
magnet with the softer spectra.

Effect of shielding on location with softer spectra



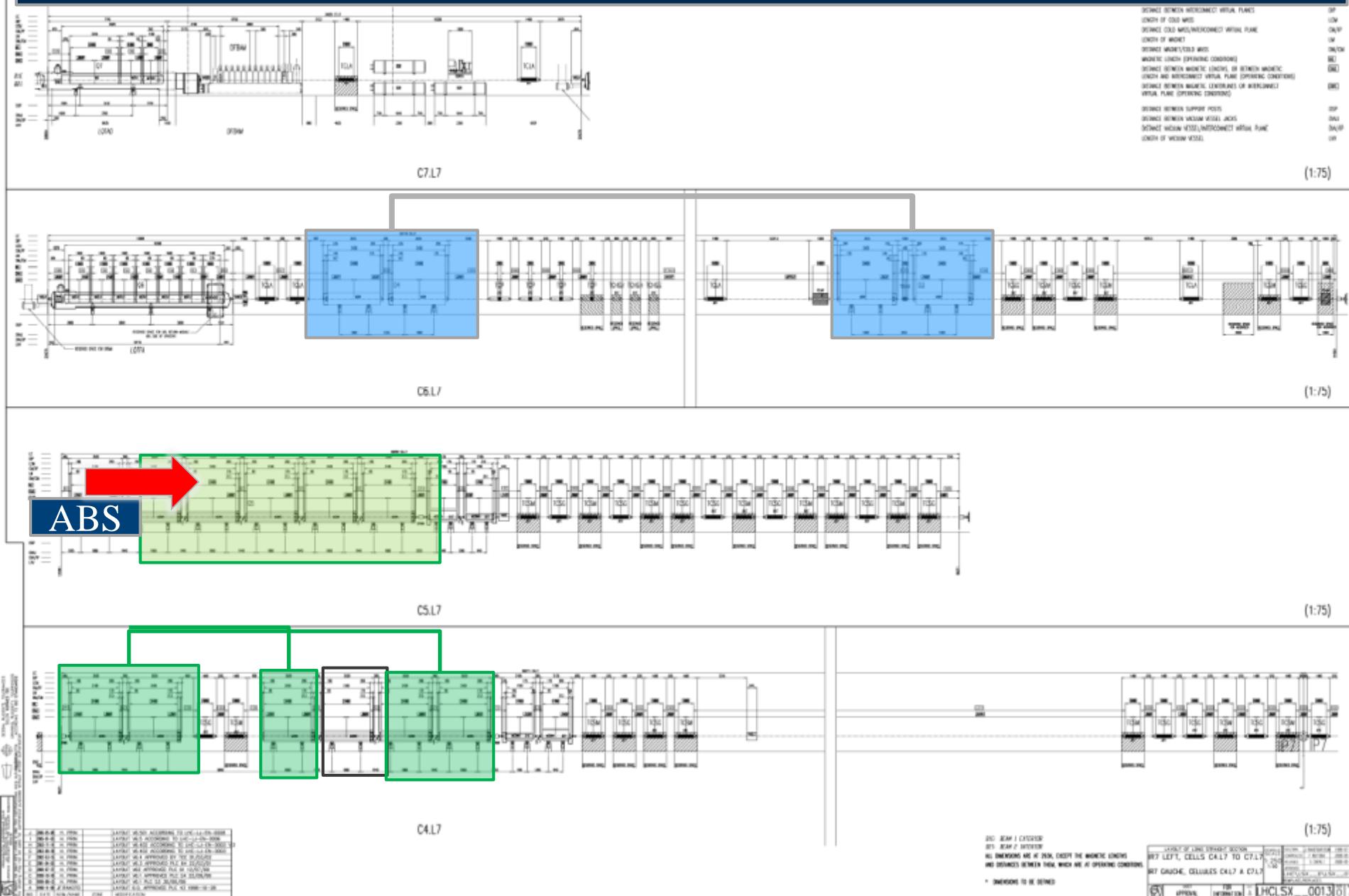
MQW shielding downstream effect not accounted for where not known



Shielding efficiency on coil doses

	$\frac{\text{dose with shielding}}{\text{dose without shielding}} \%$	remark
MQWB.4	30%	Conservative assumption: average computed efficiency
MQWA.C4	30%	Conservative assumption: average computed efficiency
MQWA.D4	30%	Conservative assumption: average computed efficiency
MQWA.E4	15%	Computed
MQWA.A5	30%	Conservative assumption: average computed efficiency
MQWA.B5	30%	Conservative assumption: average computed efficiency
MQWB.5	30%	Conservative assumption: average computed efficiency
MQWA.C5	25%	Computed
MQWA.D5	34%	Assumption same value as MQWA.E5
MQWA.E5	34%	Computed
MBW.A6	31%	Computed
MBW.B6	33%	Computed

Optic change proposal point 7 discussed and agreed as possible with M. Giovannozzi (it needs verification)



	Dose [MGy] for integrated luminosity 150 fb ⁻¹		Dose [MGy] for integrated luminosity 350 fb ⁻¹		Dose [MGy] for integrated luminosity 3000 fb ⁻¹	
	R	L	R	L	R	L
MQWA.A4	0	0	0	0	2	4
MQWA.B4	0	0	0	0	2	4
MQWB.4	0	0	0	1	2	4
MQWA.C4	0	0	0	1	3	6
MQWA.D4	0	1	1	2	7	14
MQWA.E4	3	2	5	13	24	
MQWA.A5	2	2	3	8	15	
MQWA.B5	3	2	4	10	19	
MQWB.5	7	5	10	24	45	
MQWA.C5	15	11	22	57	106	
MQWA.D5	4	3	5	14	25	
MQWA.E5	7	5	10	25	47	
MBW.A6	2	4	3	15	27	
MBW.B6	2	5	3	17	31	
MBW.C6	3	7	5	24	44	

MQW	MBW
From 10 to 20 MGy	From 40 to 60 MGy
From 20 to 50 MGy	From 60 to 80 MGy
Larger than 50 MGy	Larger than 80 MGy

	Dose [MGy] for integrated luminosity 150 fb ⁻¹		Dose [MGy] for integrated luminosity 350 fb ⁻¹		Dose [MGy] for integrated luminosity 3000 fb ⁻¹	
	R	L	R	L	R	L
MQWA.A4	1	1	1	2	10	15
MQWA.B4	0	1	1	3	9	22
MQWB.4	1	2	1	3	6	14
MQWA.C4	6	6	9	9	41	41
MQWA.D4	2	2	4	4	24	24
MQWA.E4	1	2	2	5	19	39
MQWA.A5	3	3	4	4	20	20
MQWA.B5	4	4	6	6	29	29
MQWB.5	4	4	6	6	29	29
MQWA.C5	2	5	3	7	11	28
MQWA.D5	3	5	6	8	34	49
MQWA.E5	14	5	32	11	278	93
MBW.A6	7	5	16	12	138	99
MBW.B6	12	6	29	14	247	123

Point 3 and 7 coil magnet damage estimation with shielding

green arrow installed LS1
yellow arrow foreseen for LS2

MQW: shimming lifetime

	Dose [MGy] for integrated luminosity 150 fb^{-1}		Dose [MGy] for integrated luminosity 350 fb^{-1}		Dose [MGy] for integrated luminosity 3000 fb^{-1}	
	R	L	R	L	R	L
MQWA.E4	0	1	1	2	9	19
MQWA.D5	1	1	2	3	13	19
MQWA.E5	10	3	23	8	200	67

- LS3: MQWA. E5 in point 7 is critical for the shimming life time for RUN III
- MQWA.D5 in point 7 and MQWA.C5 and MQWB.5 in point 3 are critical for HL-LHC

Conclusion

- Scope
 - 4 rad hard MQW to be installed in LS4
 - 2 in Point 7 and 2 in Point 3 (Point large margin because of the present collimation settings)
 - 4 rad hard MQW to be kept as spare
 - Radiation hardness level :
 - WITH SHIELDING
 - Coils 150 MGy
 - Supporting elements 40 MGy
 - WITHOUT SHIELDING
 - Coils 350 MGy
 - Supporting elements 80 MGy
- Next steps
 - Confirmation of rad hardness: this summer
 - Confirmation of dose for bench mark dosimeter and FLUKA computations: late spring

annexes

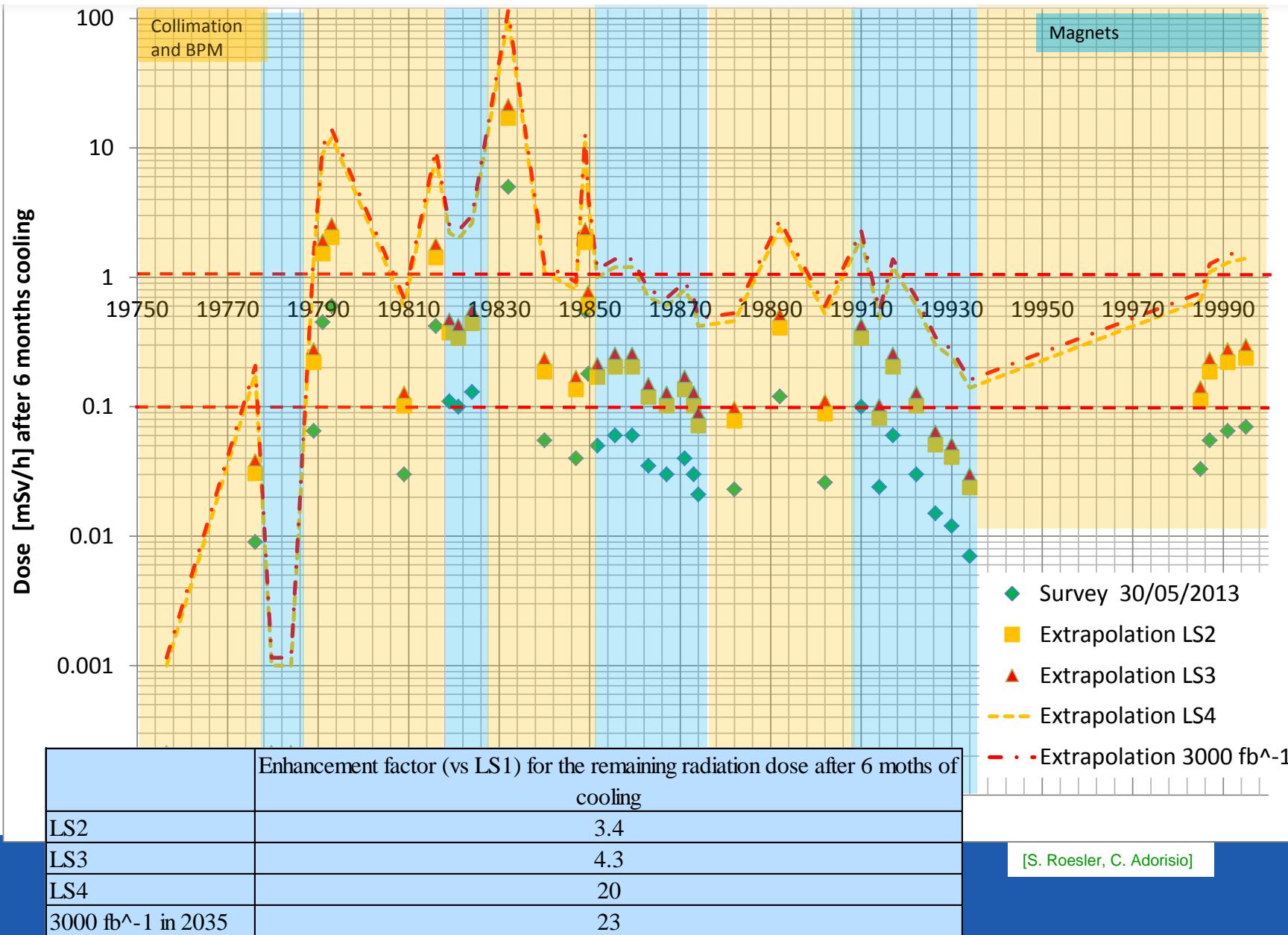
IMPROVING KNOWLEDGE, CONFIDENCE IN DATA AND POSSIBLE DEVELOPMENTS



Radiation hard coils: under study

Proposal	Remark
Effect of replacing E glass with S2 glass	From test in Fraunhofer
Effect of replacing E glass with Mica	From test in Fraunhofer
Replacing epoxy with Cyanate ester bled	Known to be good, synergies with the MCBXFA/B development at CIEMAT
MgO insulated cables	Contact established with KEK and ITER, to go deeper in next months

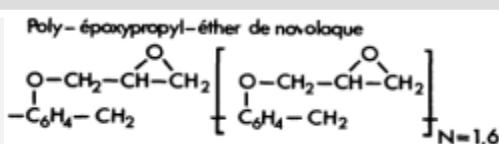
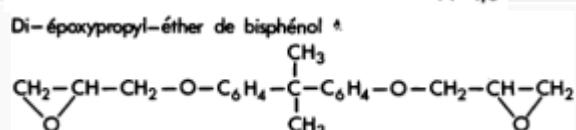
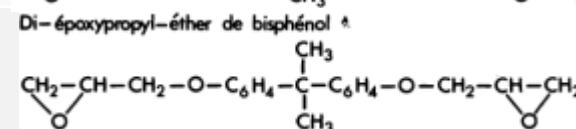
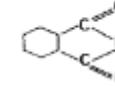
POINT 7 residual dose at 40 cm after 6 months of cooling

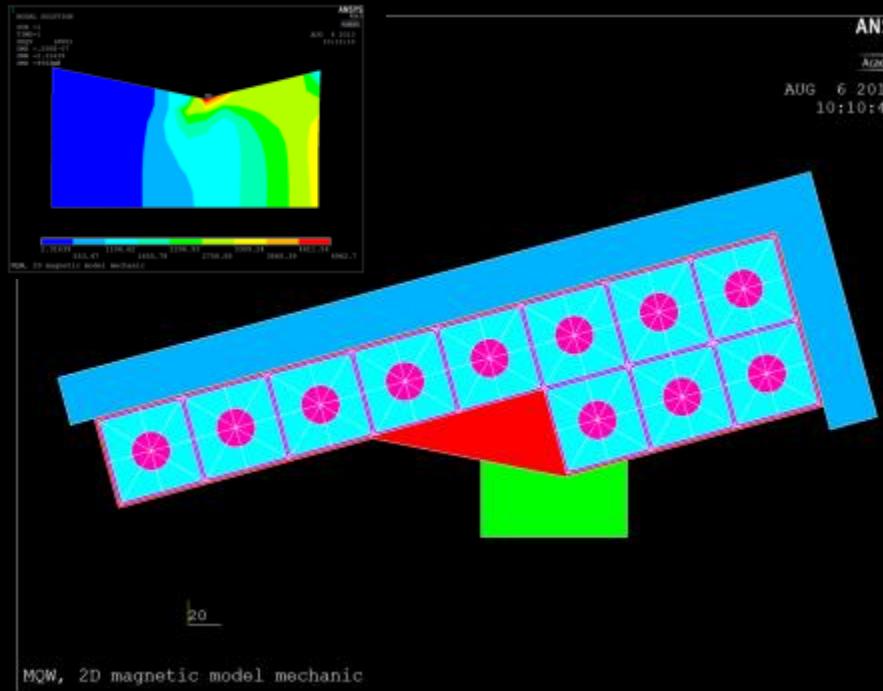


MATERIAL PROPERTIES

MQW coil resins

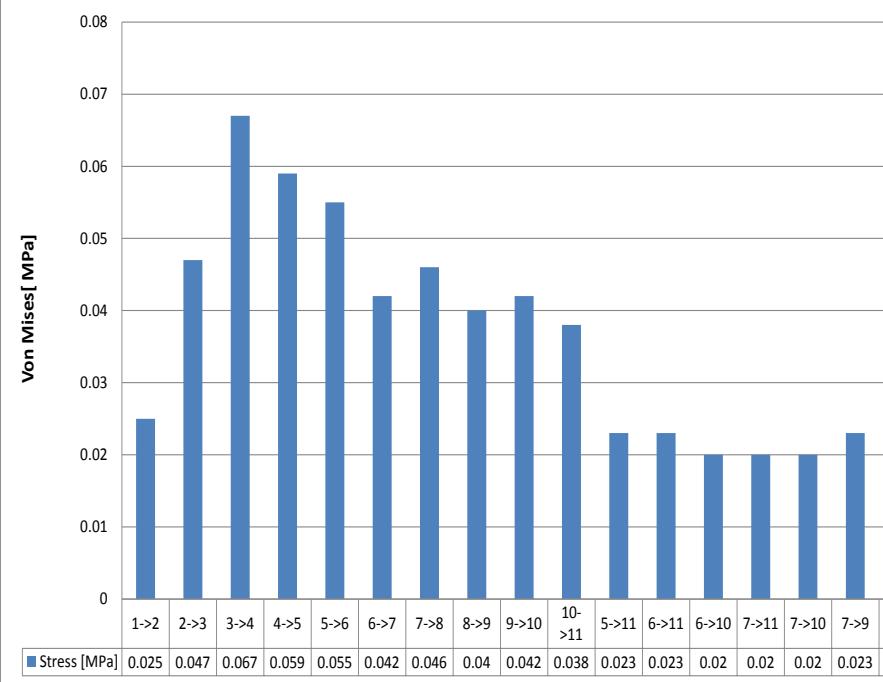
Resin used					
component	EPN1138	GY 6004	CY 221	HY 905	30ml DY 073
ppw	50	50	20	120	0.03

EPN 1138	Novolac	Poly-époxypropyl-éther de novolaque 	
GY 6004	DGEBA	Di-époxypropyl-éther de bisphénol A 	
CY 221	DGEBA	Di-époxypropyl-éther de bisphénol A 	
HY 905	HY 905 (CIBA-GEIGY) HPA	Acid anhydride hardener, liquid, modified Hexahydrophthalic anhydride (see HT 907)	HT 907 (CIBA-GEIGY) Acid anhydride hardener, solid, unmodified Hexahydrophthalic anhydride 
DY 073	flexibilizer		



MQW, 2D magnetic model mechanic

MQW stresses in turn to turn insulation I=710 A



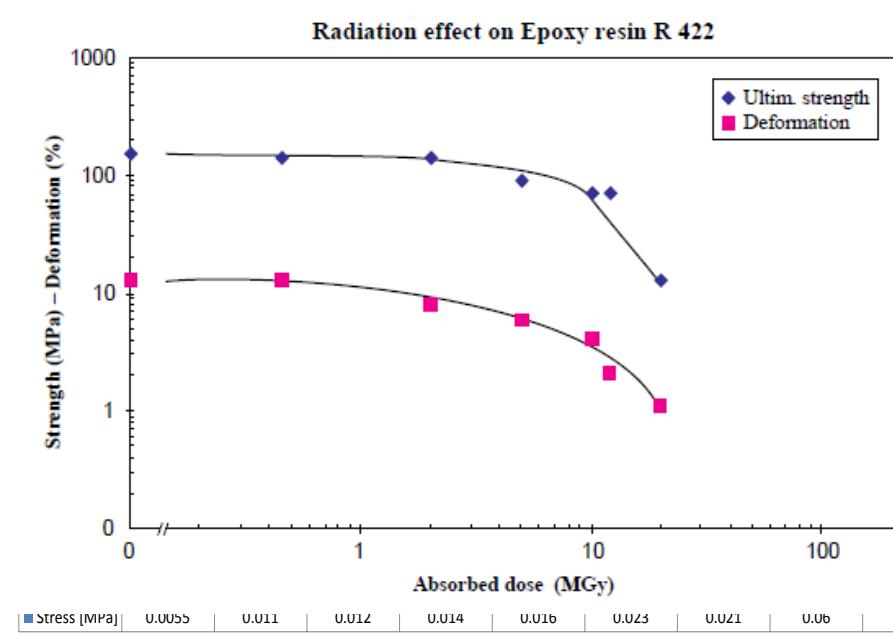
CERN 98-01/A3/E

Material: Epoxy resin
Type: MY 745 (50) + EPN 1138 (50) + CY 221 (20) + HY 905 (120) + DY 073 (0.3)

TIS No. R 422

Supplier: Ciba-Geigy
Remarks: used for the ISR dipoles

UL 94: n.m.
LOI:



No.	Material and Supplier	Dose (Gy)	Ultimate flex. strength S (N/mm ²)	Deflexion at break D (mm)	Modulus of elasticity M (N/mm ²)
89	EPN 1138(50) + MY 745(50) + + CY 221(20) + HY 905(120) + + DY 063(0.3) 24 h 120 °C Type ISR ALSTHOM	0 6×10^6 1×10^7 2×10^7 6×10^7	131.5 ± 24.5 92.2 ± 6.9 68.7 ± 22.6 62.8 ± 13.7 6.9 ± 0.3	9.3 ± 3.2 4.6 ± 0.3 3.5 ± 1.2 3.0 ± 0.7 0.7 ± 0.1	$3.55 \pm 0.15 \times 10^3$ $3.75 \pm 0.13 \times 10^3$ $3.56 \pm 0.07 \times 10^3$ $3.88 \pm 0.08 \times 10^3$ $1.90 \pm 0.24 \times 10^3$
123	EPN 1138(50) + MY 745(50) + + HY 905(103) + XB 2687(0.25) 24 h 120 °C ALSTHOM	0 5×10^6 1×10^7 2×10^7	118.7 ± 21.6 114.8 ± 21.6 78.5 ± 8.8 53.0 ± 6.9	8.4 ± 3.1 9.8 ± 3.4 4.3 ± 0.4 2.8 ± 0.3	$3.30 \pm 0.05 \times 10^3$ $3.34 \pm 0.12 \times 10^3$ $3.45 \pm 0.13 \times 10^3$ $3.51 \pm 0.06 \times 10^3$
203	EPN 1138(100) + HY 906(95) + + DY 062(0.5) 2.5 h 80 °C + 12 h 160 °C CIBA-GEIGY	0 5×10^6 1×10^7	130.5 ± 19.6 115.8 ± 19.6 122.6 ± 7.8	8.7 ± 2.2 7.1 ± 1.8 7.2 ± 0.7	$3.52 \pm 0.05 \times 10^3$ $3.88 \pm 0.17 \times 10^3$ $3.95 \pm 0.04 \times 10^3$
297	EPN 1138(50) + MY 745(50) + + CY 221(20) + HY 905(120) + + XB 2687(0.3) 24 h 120 °C CIBA-GEIGY	0 5×10^6 1×10^7 2.5×10^7 5×10^7	124.2 ± 24.5 91.9 ± 8.8 68.9 ± 11.8 13.7 ± 0.3 2.1 ± 0.0	12.4 ± 3.7 6.4 ± 0.6 4.5 ± 0.9 1.2 ± 0.4 0.7 ± 0.0	$3.73 \pm 0.25 \times 10^3$ $3.80 \pm 0.13 \times 10^3$ $4.01 \pm 0.09 \times 10^3$ $3.26 \pm 0.04 \times 10^3$ $5.27 \pm 0.00 \times 10^3$

No.	Material and Supplier	Dose (Gy)	Ultimate flex. strength S (N/mm ²)	Deflexion at break D (mm)	Modulus of elasticity M (N/mm ²)
103 (a)	CY 222 + HY 920 (Pure resin) BBC Baden	0 5×10^6 1×10^7 3×10^7 5×10^7		too flexible for testing	

MY745 replaced by GY6004

No.	Material and Supplier	Dose (Gy)	Ultimate flex. strength S (N/mm ²)	Deflexion at break D (mm)	Modulus of elasticity M (N/mm ²)
240 (a)	MY 745(100) + HY 906(90) + + XB 2687(1.5) 12 h 125 °C CIBA-GEIGY	0	118.8 ± 10.0	6.5 ± 0.8	$3.64 \pm 0.07 \times 10^3$
298	MY 745(100) + HY 906(90) + + XB 2687(1.5) 5 h 110 °C + 16 h 125 °C CIBA-GEIGY	0 5×10^6 1×10^7 2.5×10^7 5×10^7	100.4 ± 37.3 118.8 ± 32.6 100.0 ± 44.1 48.1 ± 17.7 13.7 ± 2.9	8.3 ± 4.0 11.2 ± 4.1 7.0 ± 3.5 2.9 ± 1.1 1.2 ± 0.4	$3.68 \pm 0.04 \times 10^3$ $3.65 \pm 0.12 \times 10^3$ $4.08 \pm 0.10 \times 10^3$ $4.20 \pm 0.21 \times 10^3$ $3.42 \pm 0.00 \times 10^3$
299	MY 745(100) + HY 906(90) + + XB 2687(1.5) 24 h 125 °C CIBA-GEIGY	0 5×10^6 1×10^7 2.5×10^7 5×10^7	107.7 ± 20.6 114.9 ± 34.3 68.7 ± 21.6 36.3 ± 8.8 8.8 ± 1.96	7.9 ± 2.0 9.3 ± 3.3 4.4 ± 1.3 2.2 ± 0.5 0.6 ± 0.2	$3.84 \pm 0.15 \times 10^3$ $3.76 \pm 0.12 \times 10^3$ $4.02 \pm 0.16 \times 10^3$ $4.25 \pm 0.24 \times 10^3$ $3.21 \pm 0.00 \times 10^3$

Filler contribution

Resins	Hardeners	Additives	Filler	Composition (p.p.)	Fig	Dose for 50% flex. (MGy)	Dose Range (MGy)
DGEBA	MDA		Papier	100-27-200	5.14	1.3	1 - 2
DGEBA	MDA		Silice	100-27-200	5.14	10	
DGEBA	MDA		Silice	100-27-200	5.18	11.4	
DGEBA	MDA		Silice (5 micron)	100-27-20	5.16	14.8	
DGEBA	MDA		Silice (20 micron)	100-27-20	5.16	14.8	
DGEBA	MDA		Silice (40 micron)	100-27-20	5.16	14.6	
DGEBA	MDA		Silice (40 micron)	100-27-200	5.17	12.1	
DGEBA	HPA	BDMA	Silice (40 micron)	100-80-2-200	5.17	<10	<10
DGEBA	MDA		Aérosil + Sulphate de Barium	100-27-2-150	5.14	15.8	15
DGEBA	MDA		Magnésie	100-27-120	5.14	18	18
DGEBA	MDA		Graphite	100-27-60	4.6	26.8	
DGEBA	MDA		Graphite	100-27-60	5.14	30.5	
(DGEBA	MDA		Alumine	100-27-220	4.7	23.5)	
DGEBA	MDA		Alumine	100-27-220	5.14	51.7	
DGEBA	MDA		Alumine	100-27-100	5.15	20.6	
DGEBA	MDA		Alumine	100-27-220	5.15	42.5	
DGEBA	MDA		Fibre de verre	100-27-50	5.19	82	
DGEBA	MDA		Fibre de verre	100-27-60	5.18	100	
EPN	MDA		Fibre de verre	100-29-50	5.19	>100	>100
TGMD	MDA		Fibre de silice	100-41-50	5.20	>100	
TGMD	DADPS		Fibre de silice	100-40-50	5.20	>100	>100

Legend
 Resin
 Linear aliphatic
 Cycloaliphatic
 Aromatic

Hardener
 Aliphatic Amine
 Aromatic Amine
 Alicyclic Anhydride
 Aromatic Anhydride

2 Categories of fillers:

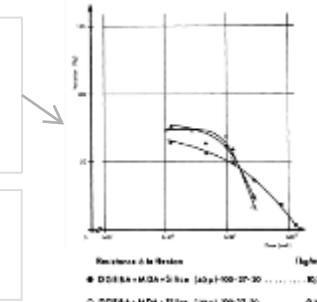
1. Powder fillers
2. Glass/Silice fibers

Paper [cellulose $(C_6H_{10}O_5)_n$]

→ Strong decrease of radio-resistance

10 - 15

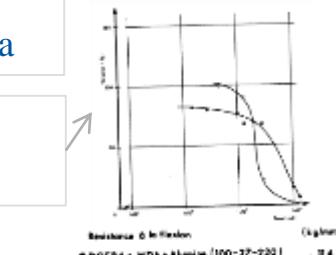
The bigger the powder, the more radio-resistant



Hardener choice not influenced by filler

25 - 30

High r.-resistance for Graphite and Alumina



20 - 50

The more fillers, the more radio-resistant

80 - 100

Best Radio-Resistant materials are obtain with Glass/Silice (influence of boron) fibers and aromatic resins (Novolac and glycidyl-amine)

EPN 1138 with filler

CY 222 (similar to CY221) with filler

CIBA-GEIGY	DOW	SHELL
EPN 1138	DEN 438	EPIKOTE (EP) 154
EPN 1139	DEN 431	

No.	Material and Supplier	Dose (Gy)	Ultimate flex. strength S (N/mm ²)	Deflexion at break D (mm)	Modulus of elasticity M (N/mm ²)
89 24 h 120 °C Type ISR	ALSTHOM	0	131.5 ± 24.5	9.3 ± 3.2	3.55 ± 0.15 × 10 ³
		6 × 10 ⁶	92.2 ± 6.9	4.6 ± 0.3	3.75 ± 0.13 × 10 ³
		1 × 10 ⁷	68.7 ± 22.6	3.5 ± 1.2	3.56 ± 0.07 × 10 ³
		2 × 10 ⁷	62.8 ± 13.7	3.0 ± 0.7	3.88 ± 0.08 × 10 ³
		6 × 10 ⁷	6.9 ± 0.3	0.7 ± 0.1	1.90 ± 0.24 × 10 ³
94	EPIKOTE 154 + MMA + glass tape	0	441.4 ± 18.6	5.5 ± 0.6	1.85 ± 0.10 × 10 ⁴
		5 × 10 ⁶	394.4 ± 12.7	5.2 ± 0.5	1.77 ± 0.06 × 10 ⁴
		1 × 10 ⁷	270.8 ± 44.2	3.6 ± 0.9	1.82 ± 0.10 × 10 ⁴
		2 × 10 ⁷	308.0 ± 21.6	4.1 ± 0.3	1.85 ± 0.11 × 10 ⁴
	MICAFIL	5 × 10 ⁷	234.5 ± 3.9	3.0 ± 0.2	1.95 ± 0.16 × 10 ⁴

MY745 replaced by GY6004 with filler

No.	Material and Supplier	Dose (Gy)	Ultimate flex. strength S (N/mm ²)	Deflexion at break D (mm)	Modulus of elasticity M (N/mm ²)
103 (a)	CY 222 + HY 920 (Pure resin)	0			
		5 × 10 ⁶			
		1 × 10 ⁷			too flexible for testing
	BBC Baden	3 × 10 ⁷	15.7 ± 2.0	5.4 ± 3.6	8.04 ± 1.32 × 10 ²
		5 × 10 ⁷	12.8 ± 1.0	1.4 ± 0.3	1.66 ± 0.13 × 10 ³
104	CY 222 + HY 920 + 70% glass (cut to fibre)	0	88.3 ± 8.8		6.87 ± 1.31 × 10 ³
		1 × 10 ⁷	114.8 ± 4.9		1.02 ± 0.09 × 10 ⁴
		3 × 10 ⁷	89.3 ± 6.9		8.34 ± 0.46 × 10 ³
	BBC Baden	6 × 10 ⁷	69.7 ± 3.9		8.44 ± 0.50 × 10 ³
		1 × 10 ⁸	61.8 ± 6.9	3.8 ± 3.5	6.07 ± 2.45 × 10 ²

Other DGBA with filler

MQW

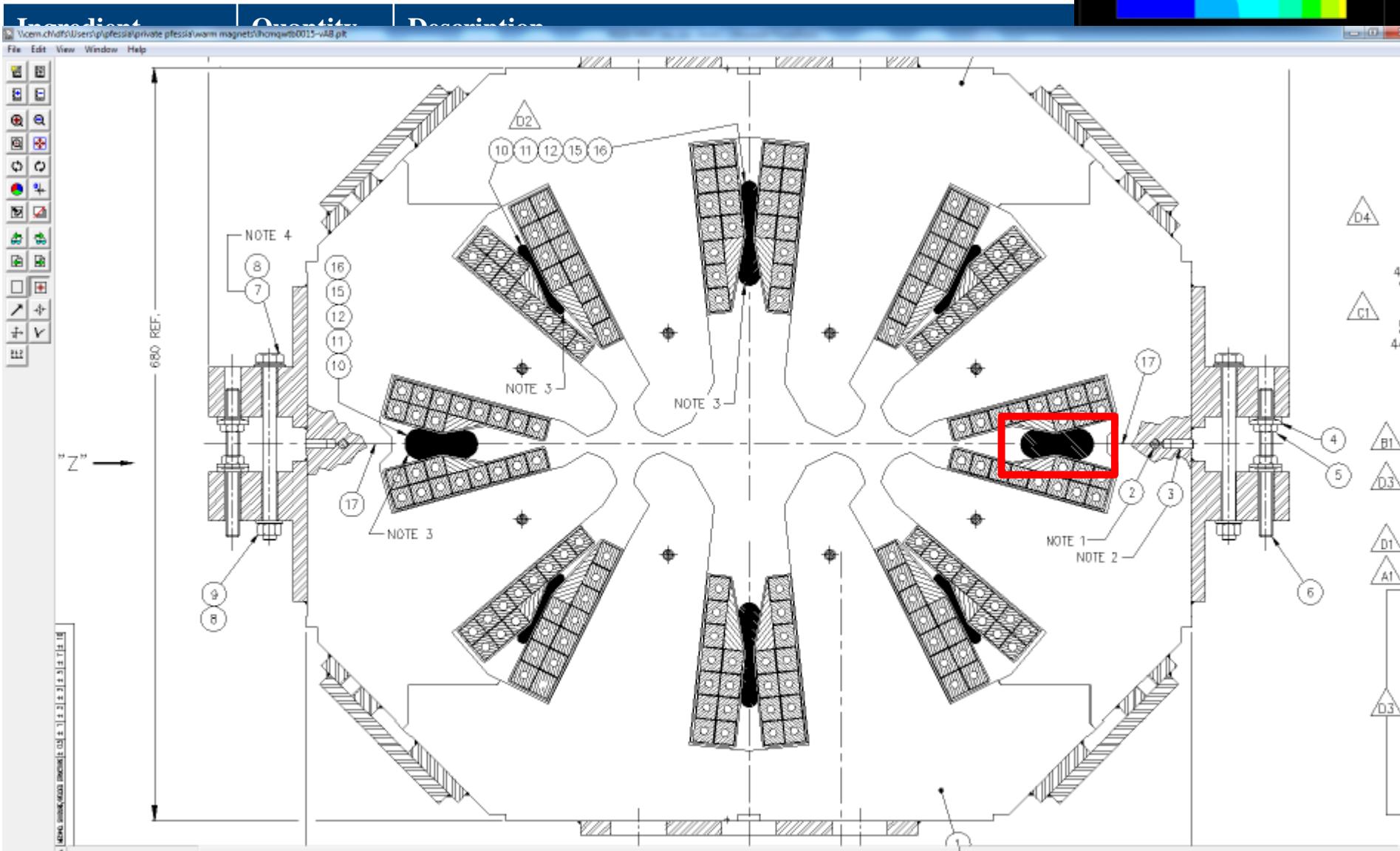
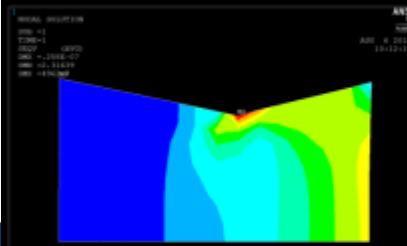
- The pure resin mix used shall keep substantial mechanical properties at least till 15-20 MGy
- Presence of glass fibre shall increase the substantial mechanical properties at least to 40-50 MGy

232									
240 (a)									
298									
299									
24 h 125 °C		1 × 10 ⁷	68.7 ± 21.6	4.4 ± 1.3	4.02 ± 0.16 × 10 ³	176	Magnet coil resin Orlitherm(B) reinforced with glass woven tape type 2 with a special silane finish	0	450.3 ± 24.5
	CIBA-GEIGY	2.5 × 10 ⁷	36.3 ± 8.8	2.2 ± 0.5	4.25 ± 0.24 × 10 ³			1 × 10 ⁷	419.9 ± 18.6
		5 × 10 ⁷	8.8 ± 1.96	0.6 ± 0.2	3.21 ± 0.00 × 10 ³			5 × 10 ⁷	387.5 ± 55.9
							12 h 165 °C BBC Baden	1 × 10 ⁸	281.5 ± 28.5
									4.9 ± 0.3
									1.44 ± 0.01 × 10 ³

Spacers resins

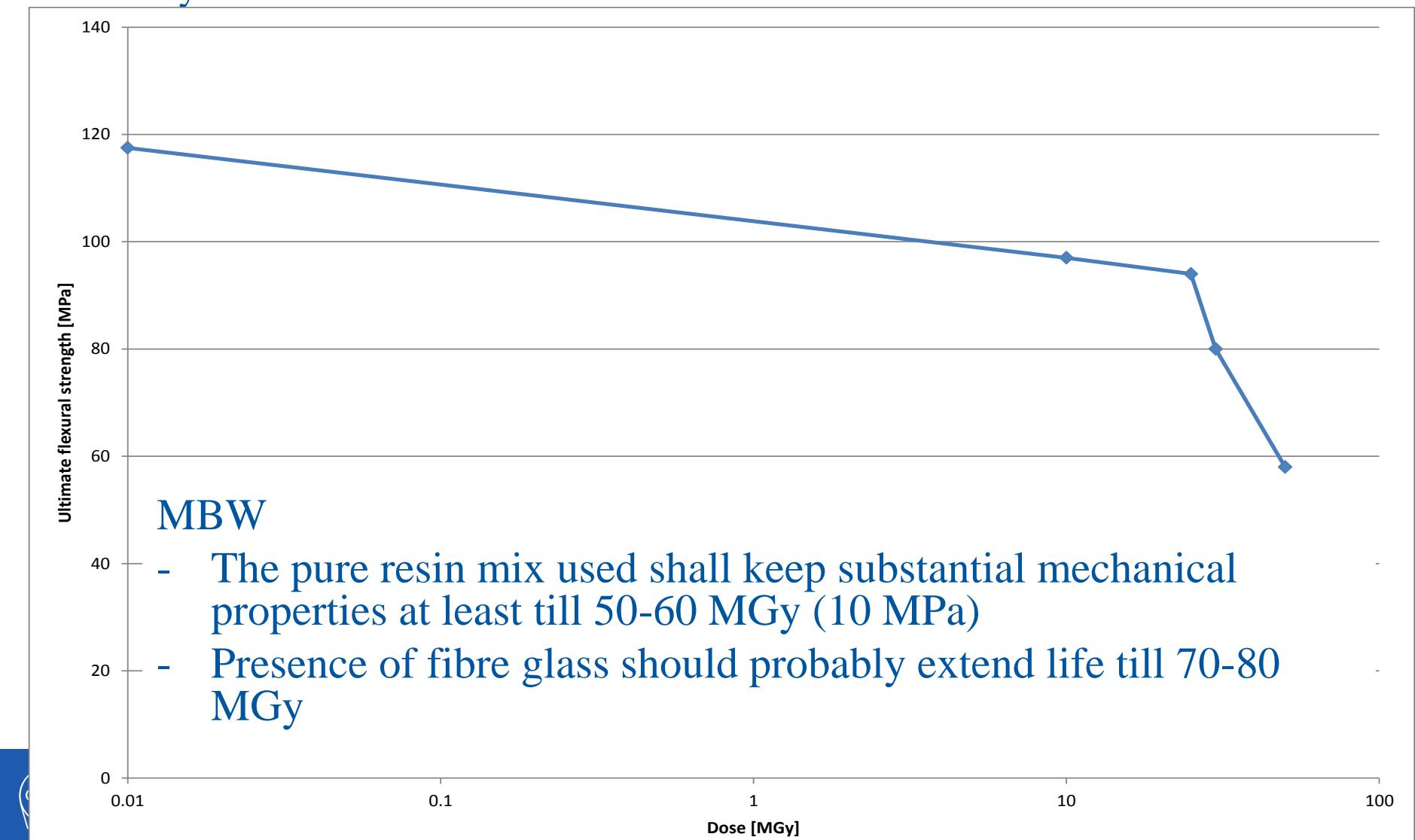
Composition

- HD polyethylene pipes filled with



MBW BINP used resin.

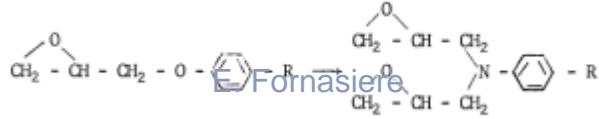
We looked at molecule and there is good indication that it should radiation hard as witnessed by the tests and we assume stresses of the order of 10 MPa



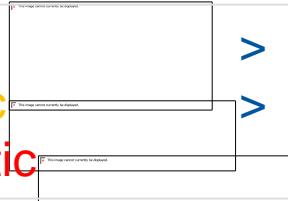
Different epoxy

Resins	Hardeners	Additives	Composition (p.p.)	Mix Temp (°C)	Viscosity (cPs)	Service life (mn)	Fig	Dose for 50% flex. (MGy)	Dose Range (MGy)
EDBAH	MA						5.4	1.4	1 - 3
EDBAH	MA	BDMA	100-105-0.2	80	45	>180	5.1	1.6	
BECP	MA						5.4	2.5	
BECP	MA	BDMA	100-110-0.2	80	40	>180	5.1	2.3	
ECC	MA		100-72	80	20	>240	5.5	1.8	1 - 6
VCD	MA	BDMA	100-160-05	60	20	>180	5.4	3.7	
DADD	MA		100-65	80	180	>240	5.4	5.5	
DGEBA + EDGDP	TETA		100-20-12	25			5.21	1.3	1 - 2
DGEBA	TETA	DBP	83-9-17	50	500	few	5.22	1.2	
DGEBA	DADPS		100-35	130	60	180	4.2	5.1	5 - 15
DGEBA + EDGDP	MDA		100-20-30	80			5.21	8.2	
DGEBA	MDA		100-27	80	100	50	5.9	13.0	
DGEBA	MPDA		100-14.5	65	200	30	5.7	23.5	
DGEBA	AE		100-40	100	150	30	5.26	45.2	5 - 15
DGEBA	DDSA	BDMA	100-130-1	80	70	120	5.2	4.2	
DGEBA	NMA	BDMA	100-80-1	80	80	120	5.2	5.9	
DGEBA	MA		100-100	60	69	>1440	5.23	7.1	
DGEBA	MA	BDMA					5.1	12.0	5 - 15
DGEBA	MA	BDMA + Po. Gl.	100-100-0.1-10	60	65	300	5.23	12.1	
DGEBA	AP	DADPS	100-70	120	26	180	5.2	13.0	
DGPP	DADPS		100-28	130			5.6	8.2	
DGPP	MA		100-135	120			5.3	13.0	
EDTC	MDA		100-20	80		40	5.9	10.0	5 - 15
TGTPE	DADPS		100-34	125	>20000		5.6	12.1	
TGTPE	MA	BDMA	100-100-0.2	125	>15000		5.3	10.6	
EPN	DADPS		100-35	100		30	5.6	23.5	
EPN	MDA		100-29	100		35	5.10	37.2	10 - 20
EPN	HPA	BDMA	100-76-1	80		40	5.10	13.0	
EPN	MA	BDMA	100-105-0.5	80		100	5.3+5.25	15.0	
EPN	NMA	BDMA	100-85-1	100		80	5.10	20.6	
TGMD	DADPS		100-40	80		50	5.6	20.6	10 - 25
TGMD	MA	BDMA	100-136-0.5	60		30	5.3	11.4	
TGMD	NMA	BDMA	100-110-1	80	500	20	5.8	18.0	
TGPAP	NMA		100-137	80	<20		5.8	23.5	
DGA	MPDA		100-20	25		120-420	5.7	23.5	20 - 30
DGA	NMA		100-115	25	5 - 20	30-5760	5.8	28.6	

Legend
 Resin
 Linear aliphatic
 Cycloaliphatic
 Aromatic
 Hardener
 Aliphatic Amine
 Aromatic Amine
 Alicyclic Anhydride
 Aromatic Anhydride



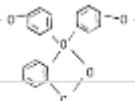
Aromatic
Cycloaliphatic
Linear Aliphatic



Aliphatic amine hardener
→ poor radio-resistance

Aromatic amine hardener
>
Anhydride hardener

H: Too high local concentration of benzene may induce steric hindrance



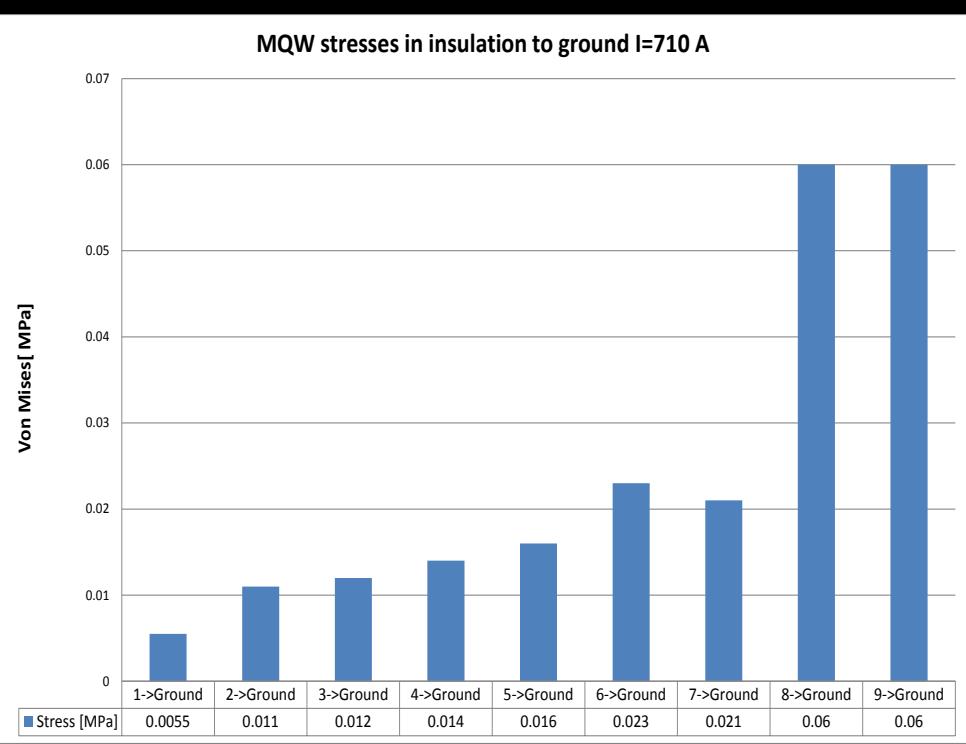
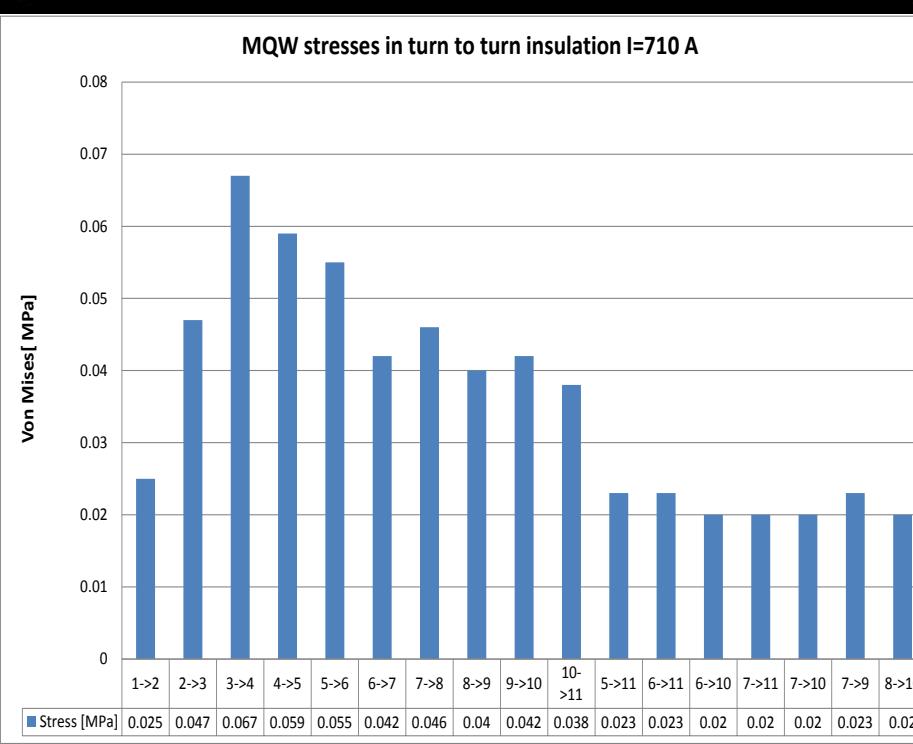
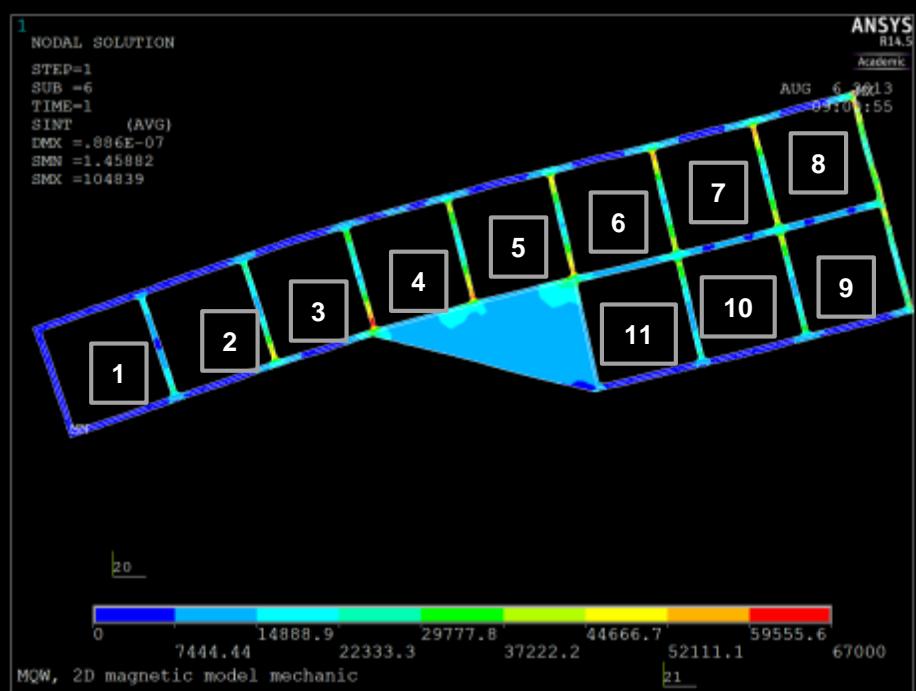
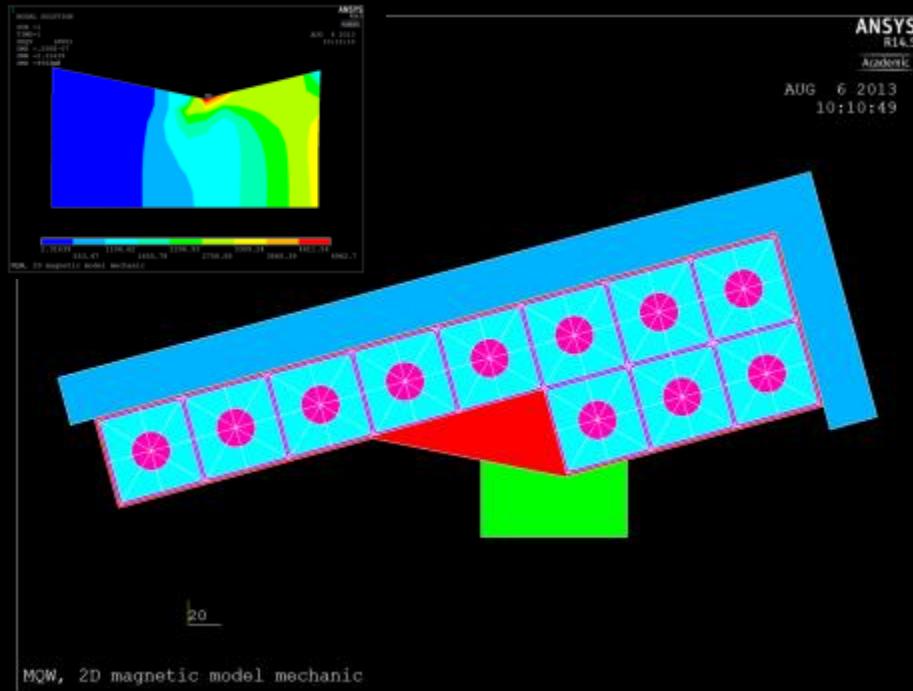
Good radio-resistance even if Cl (tendency to capture n_th)

Novolac: HIGH Radio-resistance

- Large nb of epoxy groups
→ Density + rigidity

Glycidyl-amine: HIGH R.-resistance

- Quaternary carbon
→ weakness
- Ether group → Repl. by
→ weakness amino



Material: Epoxy resin
 Type MY 745 (50) + EPN 1138 (50) + CY 221
 (20) + HY 905 (120) + DY 073 (0.3)

Supplier: Ciba-Geigy
 Remarks: used for the ISR dipoles

TIS No. R 422

UL 94: n.m.
 LOI:

Material: Epoxy resin
 Type MY 745 (50) + EPN 1138 (50) +
 CY 221 (20) + HY 905 (120) +
 DY 073 (0.3)

Supplier: Ciba-Geigy
 Remarks: used for the ISR dipoles

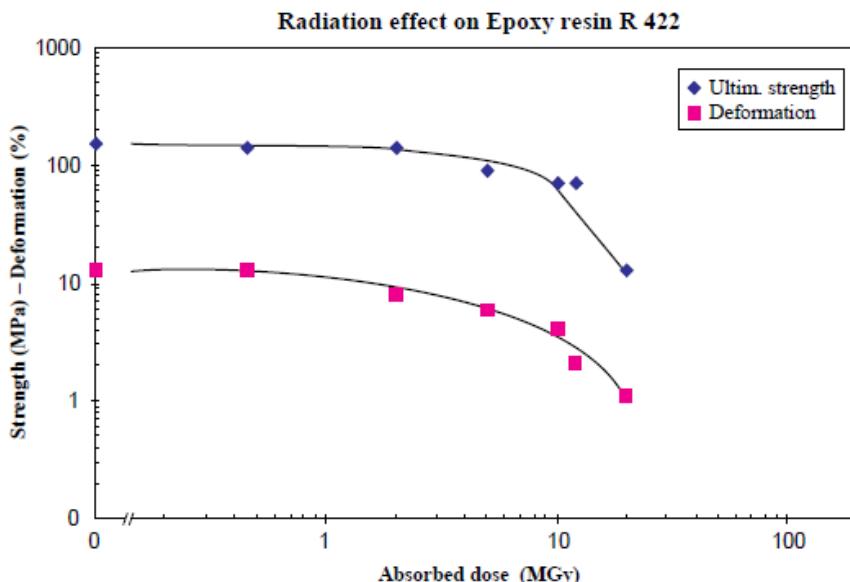
UL 94: n.m.
 LOI:

Radiation test results according to IEC Standard 544 (and ISO 178)

Dose rate (kGy/h)	Dose (MGy)	Ultim. strength (MPa)	Deformation ε (%)	Modulus (GPa)
0	0	153±3	13.1±1.9	3.80±0.03
0.2	0.5	142±1	12.9±0.3	3.50±0.02
0.2	2.0	140±1	7.9±0.3	3.50±0.02
180	5	93±2	6.1±0.3	4.00±0.03
180	10	73±3	4.2±0.2	4.10±0.04
0.5	12	71±6	2.1±0.2	3.7±0.1
180	20	13±1	1.1±0.1	3.40±0.04

Radiation index (RI) = 6.9 if strength is the critical property

Radiation index (RI) = 6.6 if deformation is the critical property



Dose (MGy)	Mechanical test results at RT			Mechanical test results at 77 K		
	Strength (MPa)	Deformation ε (%)	Modulus (GPa)	Strength (MPa)	Deformation ε (%)	Modulus (GPa)
0	152.6 ± 3.0	13.1 ± 1.9	3.8 ± 0.03	344 ± 19	3.5 ± 0.5	6.7 ± 0.9
5	93.0 ± 2.0	6.1 ± 0.3	4.0 ± 0.03			
10	73.0 ± 3.0	4.2 ± 0.2	4.1 ± 0.04	191 ± 13	3.5 ± 0.3	5.3 ± 0.2
14				124 ± 44	2.0 ± 0.1	6.1 ± 0.7
20	13.0 ± 1.0	1.1 ± 0.1	3.4 ± 0.04	18 ± 5.0	0.7 ± 0.2	2.8 ± 1.0
35						
119						
RI =	6.9	6.6	> 7.3	> 7.3	7.7	7.7

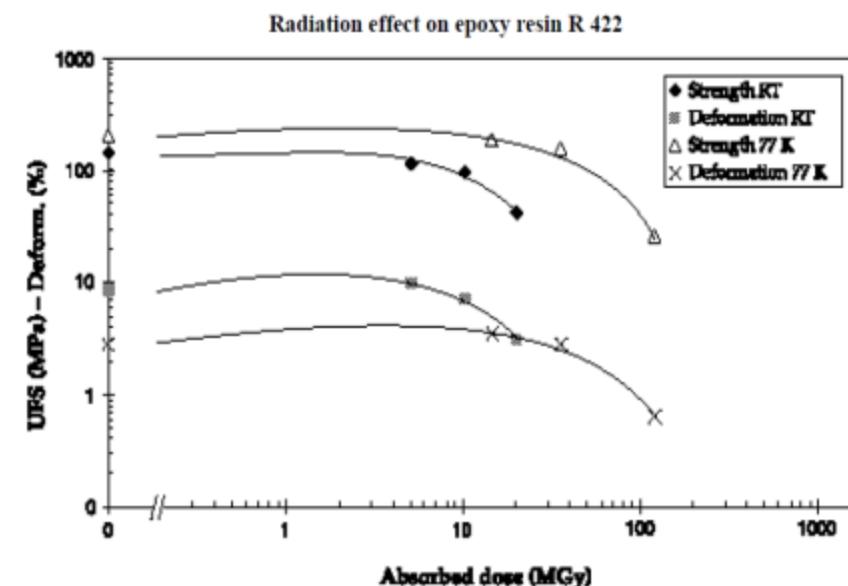
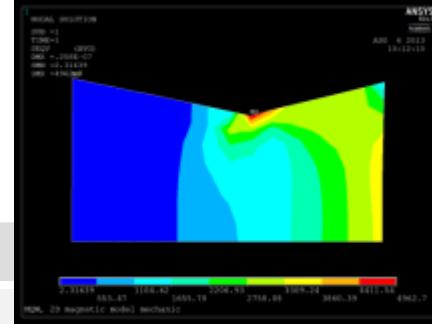


Fig. 18: Araldite MY 745 + EPN 1138 R 422

Spacers resins

Composition

- HD polyethylene pipes filled with



Ingredient	Quantity	Description
EPON 826	22 kg	Low viscosity, liquid bisphenol A based epoxy resin.
RP 1500	3kg	Tetramine hardener
MIN-SIL 120 F	17 kg	Fused silica particles 50% diameter smaller than 0.044 mm

ARALDITE F
CY205

- 39 -

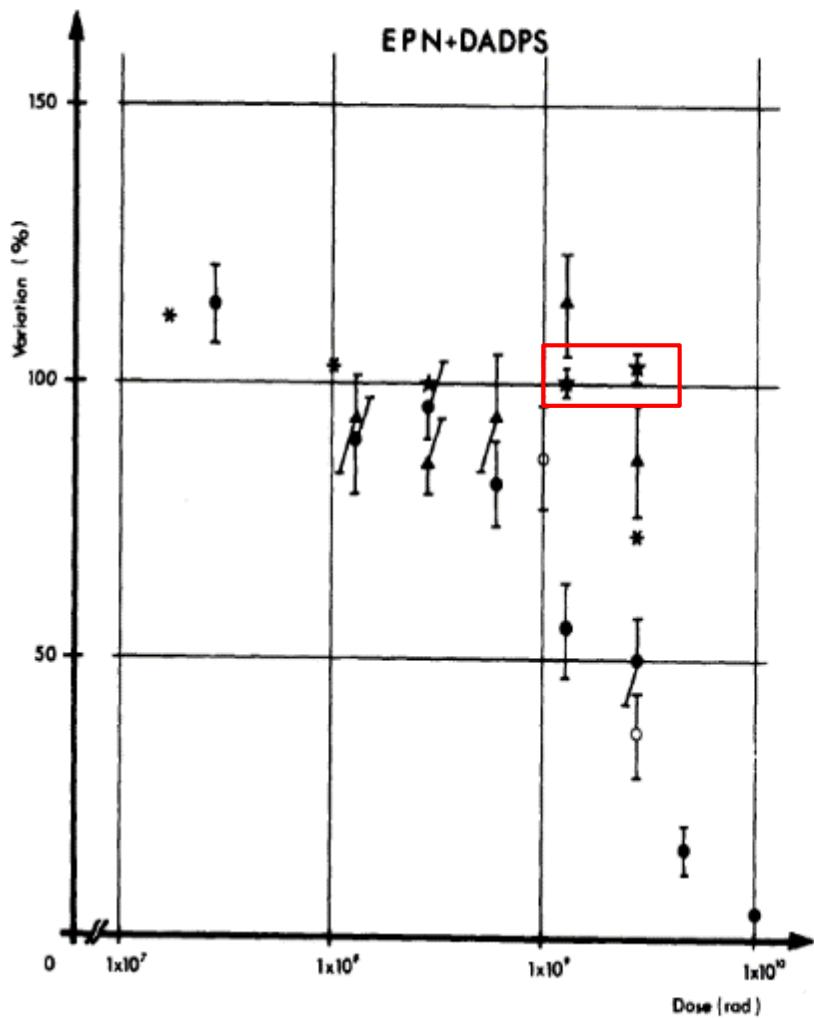
No.	Material and Supplier	Dose	Ultimate flex. strength S (N/mm²)	Deflexion at break D (mm)	Modulus of elasticity M (N/mm²)
97	Magnet coil resin Orlit-therm® (Base: DGEBF + MMA + other components) BBC Baden	0	97.1 ± 16.7	5.8 ± 1.7	3.53 ± 0.11 × 10 ³
		5.6 × 10 ⁵	64.7 ± 10.8	3.6 ± 0.6	3.91 ± 0.06 × 10 ³
		1.1 × 10 ⁶	52.9 ± 14.7	3.0 ± 0.8	3.55 ± 0.13 × 10 ³
		2.2 × 10 ⁶	39.2 ± 6.8	2.0 ± 0.4	3.75 ± 0.15 × 10 ³
99	Magnet coil resin Orlit-therm® reinforced with fibre-reinforced woven glass tape type 1 and mica-paper tape BBC Baden	0	226.6 ± 11.7	5.0 ± 0.5	2.95 ± 0.74 × 10 ³
		1.1 × 10 ⁵	191.3 ± 2.9	5.2 ± 0.4	7.99 ± 0.54 × 10 ³
		3.1 × 10 ⁵	130.4 ± 5.9	4.6 ± 0.5	8.00 ± 0.50 × 10 ³
		6.3 × 10 ⁵	84.4 ± 14.7	3.9 ± 0.5	5.85 ± 0.49 × 10 ³
131	ARALDITE F(100) + MMA(80) + IMMA(0.5) + filler Rutherford Workshop	0	312.9 ± 2.9	9.0 ± 0.3	1.57 ± 0.05 × 10 ⁴
		1 × 10 ⁵	267.4 ± 11.8	8.9 ± 0.1	1.48 ± 0.02 × 10 ⁴
		2 × 10 ⁵	301.2 ± 8.8	10.2 ± 0.3	1.51 ± 0.02 × 10 ⁴
		5 × 10 ⁵	222.7 ± 2.9	9.8 ± 0.4	1.89 ± 0.05 × 10 ⁴
132	ARALDITE F + MMA + filler LISIMOTTE	0	436.5 ± 55.9	6.8 ± 0.8	2.42 ± 0.07 × 10 ⁴
		5 × 10 ⁴	392.4 ± 20.5	6.3 ± 0.5	2.24 ± 0.13 × 10 ⁴
		1 × 10 ⁵	402.2 ± 54.0	6.8 ± 1.0	2.19 ± 0.22 × 10 ⁴
		2 × 10 ⁵	365.9 ± 53.0	6.4 ± 0.6	2.35 ± 0.22 × 10 ⁴
149	CY 205(100) + HY 906(130) + DY 040(20) + BF 064(0.5) 40 h 75 °C CIBA-GEIGY	0	78.6 ± 0.98	8.4 ± 0.4	2.12 ± 0.05 × 10 ³
		5 × 10 ⁴	49.6 ± 30.4	6.2 ± 5.3	2.14 ± 0.05 × 10 ³
		1 × 10 ⁵	56.9 ± 3.8	5.2 ± 0.5	2.18 ± 0.01 × 10 ³
		3 × 10 ⁵	samples broken after Irradiation		
150	CY 205(100) + HY 906(130) + DY 040(20) + BF 064(0.5) + Silica 40 h 75 °C CIBA-GEIGY	0	83.4 ± 2.9	2.4 ± 0.3	8.36 ± 0.37 × 10 ³
		5 × 10 ⁴	56.9 ± 4.9	1.7 ± 0.1	9.98 ± 0.39 × 10 ³
		1 × 10 ⁵	42.2 ± 3.9	0.9 ± 0.1	9.40 ± 0.29 × 10 ³
		3 × 10 ⁵	samples broken after Irradiation		

Assume a limit of
20 MGy

No.	Material and Supplier	Dose	Ultimate flex. strength S (N/mm²)	Deflexion at break D (mm)	Modulus of elasticity M (N/mm²)
320	ARALDITE D + HY 956 (Cured at ambient temp.)	0	92.2 ± 12.8	5.9 ± 1.6	2.78 ± 0.05 × 10 ³
		2 × 10 ⁴	46.1 ± 31.4	2.2 ± 1.7	2.82 ± 0.27 × 10 ³
		6 × 10 ⁴	23.5 ± 10.8	1.1 ± 0.6	2.44 ± 0.38 × 10 ³
		2 × 10 ⁷	samples broken after irradiation		
321	ARALDITE D + HY 956 filled with cotton (Cured at ambient temp.)	0	91.2 ± 3.9	6.3 ± 1.3	3.82 ± 0.09 × 10 ³
		2 × 10 ⁴	21.6 ± 3.9	1.1 ± 0.3	2.84 ± 0.06 × 10 ³
		6 × 10 ⁴	22.6 ± 3.9	1.3 ± 0.4	2.25 ± 0.32 × 10 ³
		2 × 10 ⁷	samples broken after irradiation		
311	CY 205(100) + HY 906(80) + DY 061(0.5) + Silica CIBA-GEIGY	0	96.1 ± 2.9	1.6 ± 0.0	9.28 ± 0.09 × 10 ³
		5 × 10 ⁴	67.7 ± 1.96	1.4 ± 0.1	9.15 ± 0.17 × 10 ³
		1 × 10 ⁵	64.5 ± 3.9	1.3 ± 0.1	9.16 ± 0.16 × 10 ³
		5 × 10 ⁷	30.6 ± 0.98	0.6 ± 0.0	7.48 ± 0.34 × 10 ³
312	CY 205(100) + HY 906(80) + DY 061(0.5) CIBA-GEIGY	0	64.9 ± 5.9	3.0 ± 0.2	3.35 ± 0.07 × 10 ³
		5 × 10 ⁴	68.7 ± 5.9	2.9 ± 0.3	3.67 ± 0.04 × 10 ³
		1 × 10 ⁵	50.0 ± 2.9	2.0 ± 0.1	3.81 ± 0.08 × 10 ³
		2.5 × 10 ⁷	32.6 ± 7.8	1.3 ± 0.3	3.93 ± 0.13 × 10 ³

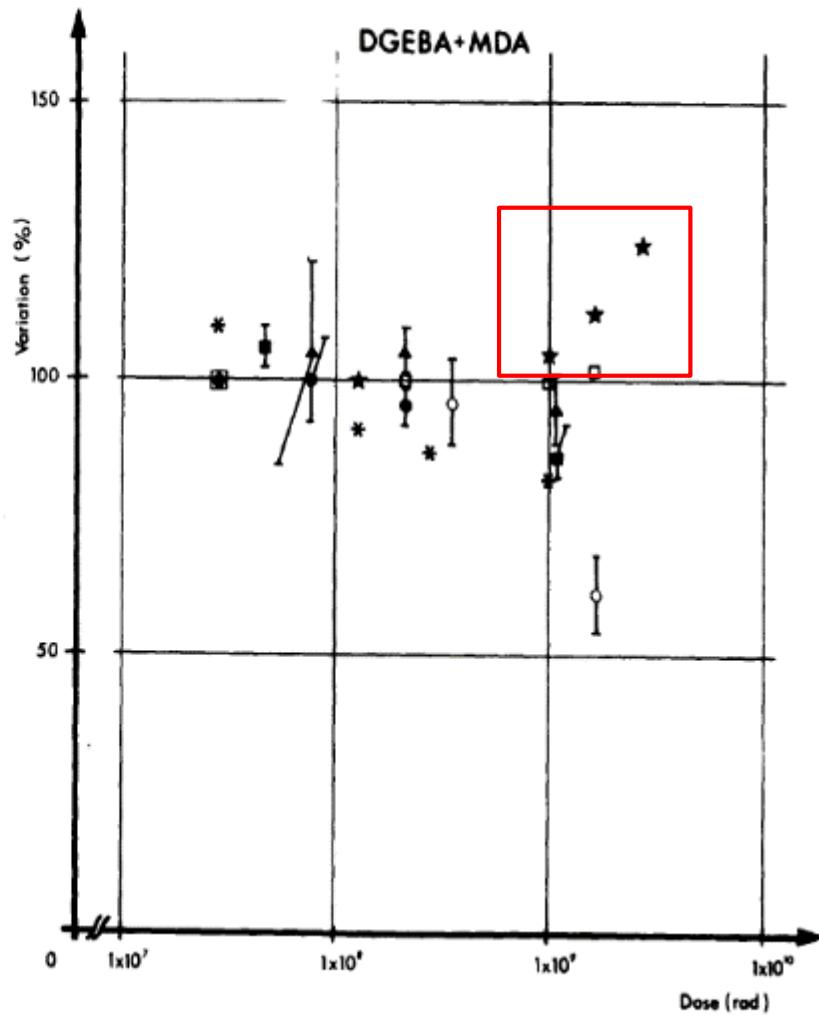
No.	Material and Supplier	Dose	Ultimate flex. strength S (N/mm²)	Deflexion at break D (mm)	Modulus of elasticity M (N/mm²)
160	CY 205(100) + HY 905(100) + DY 040(10) + Silica(400) + DY 061(1) CIBA-GEIGY	0	51.0 ± 3.9	1.4 ± 0.1	1.02 ± 0.02 × 10 ³
		5 × 10 ⁴	50.0 ± 2.0	1.3 ± 0.0	1.27 ± 0.25 × 10 ³
		1 × 10 ⁵	29.4 ± 2.0	0.9 ± 0.1	1.10 ± 0.07 × 10 ³
		5 × 10 ⁷	27.8 ± 4.9	1.1 ± 0.1	8.13 ± 1.20 × 10 ³





Modifications des propriétés mécaniques du EPN+DADPS
en fonction des doses absorbées

● 1 - Résistance à la flexion	14,5	kg/mm ²
○ 2 - Résistance à la traction	9,1	kg/mm ²
▲ 3 - Module d'élasticité	245	kg/mm ²
△ 4 - Allongement à la rupture	mm	
■ 5 - Résistance au choc	kg-m/cm ²	
□ 6 - Durété	Shore D	
★ 7 - Absorption d'eau -25°C , 4 jours	0,5	%
* 8 - Point de fléchissement à la chaleur	216	°C



Modifications des propriétés mécaniques du DGEBA+MDA
en fonction des doses absorbées

● 1 - Résistance à la flexion	17	kg/mm ²
○ 2 - Résistance à la traction	7,2	kg/mm ²
▲ 3 - Module d'élasticité	325	kg/mm ²
△ 4 - Allongement à la rupture	mm	
■ 5 - Résistance au choc	25	kg-m/cm ²
□ 6 - Durété	86	Shore D
★ 7 - Absorption d'eau -25°C , 4 jours	0,6	%
* 8 - Point de fléchissement à la chaleur	158	°C

Table 1

Technical application, composition, curing conditions, and short survey
on properties of the tested impregnation systems based on ARALDITE® and ARACAST® epoxy resins

Type	1	2 and 2a	3	4	5
Technical application CERN	Vacuum impregnation of ISR magnet coils	Vacuum impregnation of SPS magnet coils	Comparative systems		
			Standard 1	Standard 2	Hydantoin
<u>Composition:</u> a)					
- Epoxy resins	EPN 1138 Araldite MY 745 Araldite CY 221	Araldite MY 745	Araldite CY 205 = Araldite F	Araldite CY 205 = Araldite F	Aracast CY 362
- Hardener	HY 905	HY 906	HY 905	HY 906	HY 905
- Accelerator	XB 2687	XB 2687	DY 061	DY 064	XB 2687
Parts per weight of the components	50:50:20:120:0.3	100:90:1.5	100:100:1	100:80:1	100:120:1.5
Curing conditions for test specimen	24 h/120 °C Type 2: 5 h/110 °C + 16 h/125 °C Type 2a: 24 h/150 °C		8 h/80 °C + 8 h/130 °C	24 h/150 °C	12 h/90 °C + 18 h/140 °C
Processing properties b)	Medium viscosity, very good long pot-life, long gel-time.	Medium viscosity, long pot-life, medium gel-time.	Medium viscosity, short pot-life, short gel-time.	Medium viscosity, short pot-life, short gel-time.	Low viscosity, long pot-life, short gel-time.
Mechanical and thermo-mechanical properties b)	Good flexibility, medium heat distortion temperature respectively glass transition temperature (medium cross-linking grade).	Good flexibility, higher transition temperature than type 1 (higher cross-linking grade). Type 2a: less flexible and higher glass transition temperature.	Good flexibility, medium glass transition temperature (medium cross-linking grade).	Medium flexibility, high glass transition temperature (high cross-linking grade).	Medium heat distortion temperature respectively glass transition temperature (medium cross-linking grade).
Electrical properties b)	Medium tracking resistance.	Good properties as a function of temperature.	Very good tracking resistance.	Good dielectrical properties as a function of temperature.	Very good tracking resistance.

a) For more details see Table 2; b) For more details see Table 3.

ARALDITE® and ARACAST® are trade names of Ciba-Geigy epoxy resins.

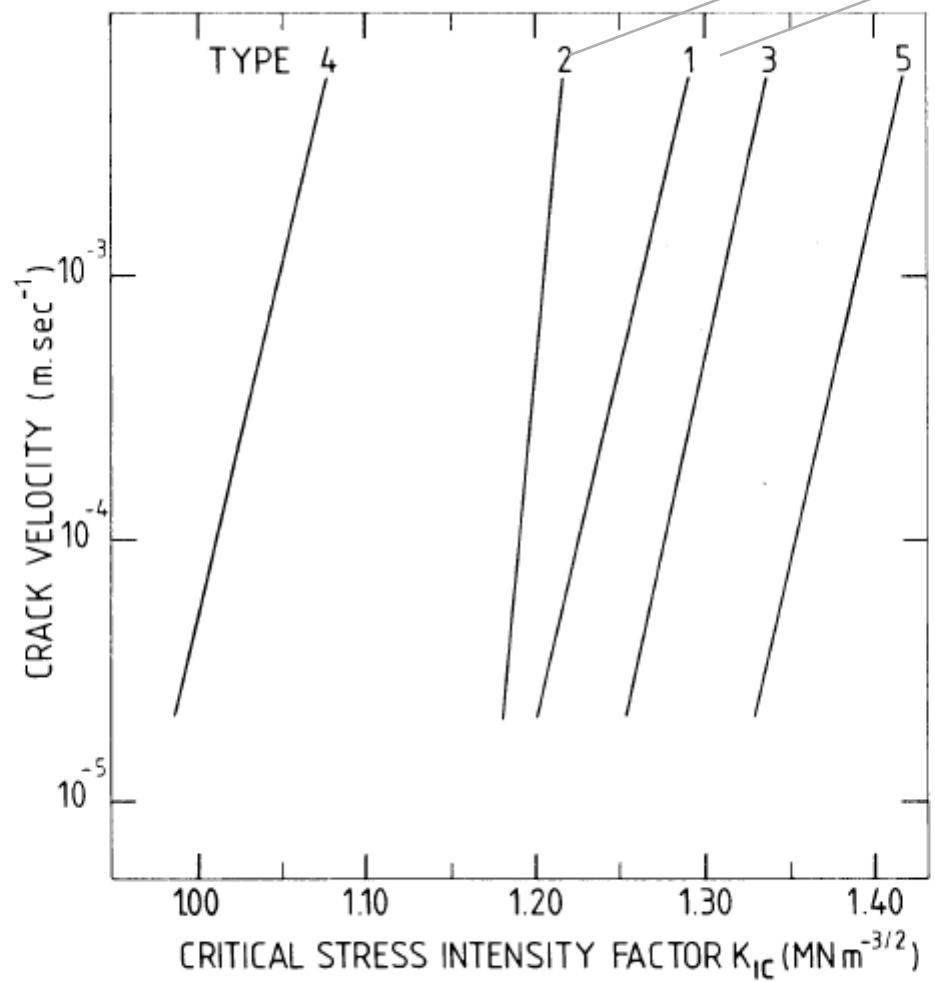
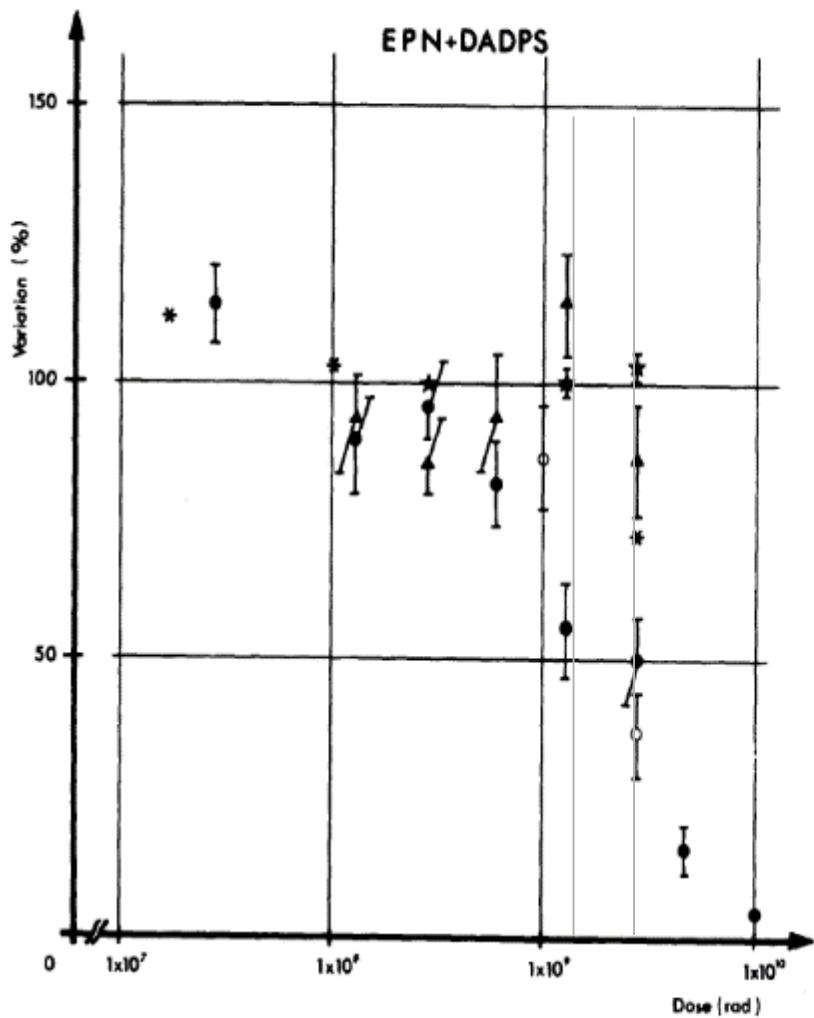
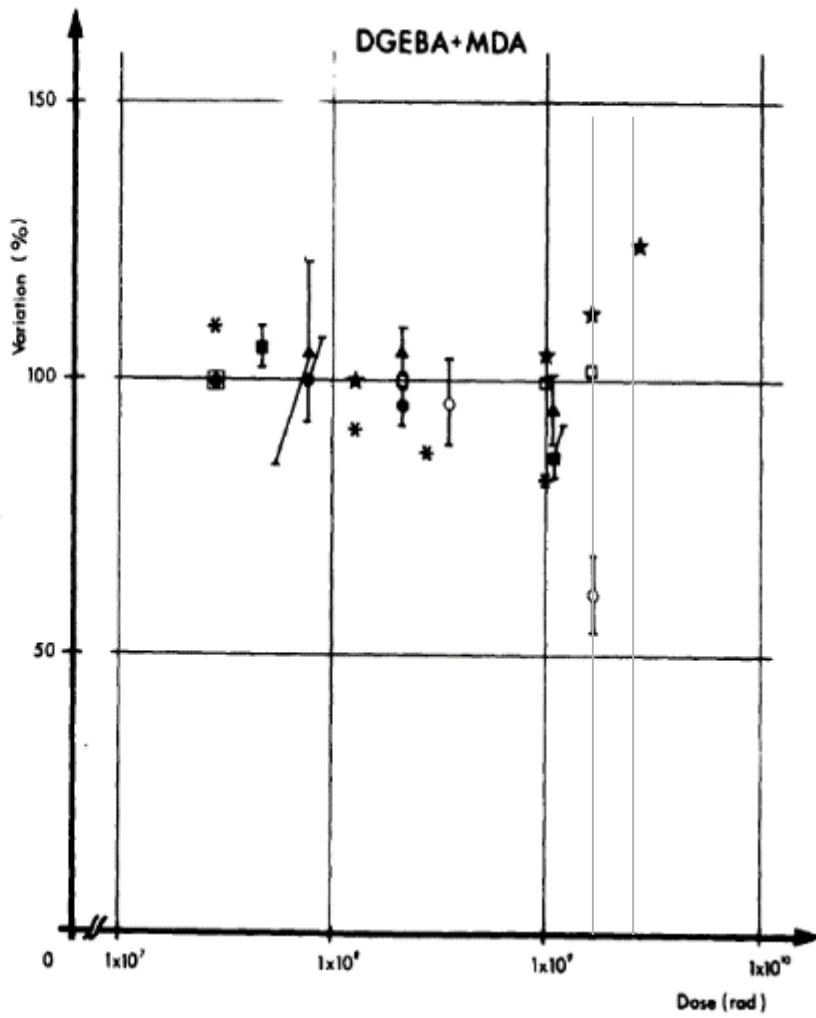


Fig. 4 Crack velocity as a function of critical stress intensity factor



Modifications des propriétés mécaniques du EPN+DADPS
en fonction des doses absorbées

● 1 - Résistance à la flexion	14,5	kg/mm ²
○ 2 - Résistance à la traction	9,1	kg/mm ²
▲ 3 - Module d'élasticité	245	kg/mm ²
△ 4 - Allongement à la rupture	mm	
■ 5 - Résistance au choc	kg-m/cm ²	
□ 6 - Durété	Shore D	
★ 7 - Absorption d'eau - 25°C , 4 jours	0,5	%
* 8 - Point de fléchissement à la chaleur	216	°C



Modifications des propriétés mécaniques du DGEBA+MDA
en fonction des doses absorbées

● 1 - Résistance à la flexion	17	kg/mm ²
○ 2 - Résistance à la traction	7,2	kg/mm ²
▲ 3 - Module d'élasticité	325	kg/mm ²
△ 4 - Allongement à la rupture	mm	
■ 5 - Résistance au choc	25	kg-m/cm ²
□ 6 - Durété	86	Shore D
★ 7 - Absorption d'eau - 25°C , 4 jours	0,6	%
* 8 - Point de fléchissement à la chaleur	158	°C

Table III.1e

Effect of nuclear radiation on the
dielectric strength of epoxy resins

Resin composition	Dielectric strength (kV/mm) versus dose (rad)						
	0	2.3×10^8	5.6×10^8	6.8×10^8	1.2×10^9	1.2×10^9	2.7×10^9
1) Araldite F + MDA	21.2 ± 0.8				$17.7 \pm 0.8(83.5)$		$16.1 \pm 0.8(76)$
2) Araldite F + DADPS	21.4 "				18.5 " (86.5)		17.5 " (82)
3) Araldite F + MA	19.0 "				18.2 " (96)		17.8 " (93.5)
4) Araldite B + AP	18.1 "				17.4 " (96)		14.5 " (80)
5) Araldite F + DPA + TETA	19.6 "	$19.5 \pm 0.8(100)$		$16.5 \pm 0.8(84)$	0		
6) EPN + MA + BDMA	22.5 "		$21.0 \pm 0.8(93.5)$			$20.0 \pm 0.8(89)$	
7) EPN + MDA	19.1 "		20.0 " (105)			18.5 " (97)	
8) TGMD + MA + BDMA	20.1 "		18.7 " (93.5)			18.0 " (90)	
9) TGMD + MDA	23.4 "		23.3 " (100)			25.2 " (108)	

The values in brackets represent the percentage of the initial value.

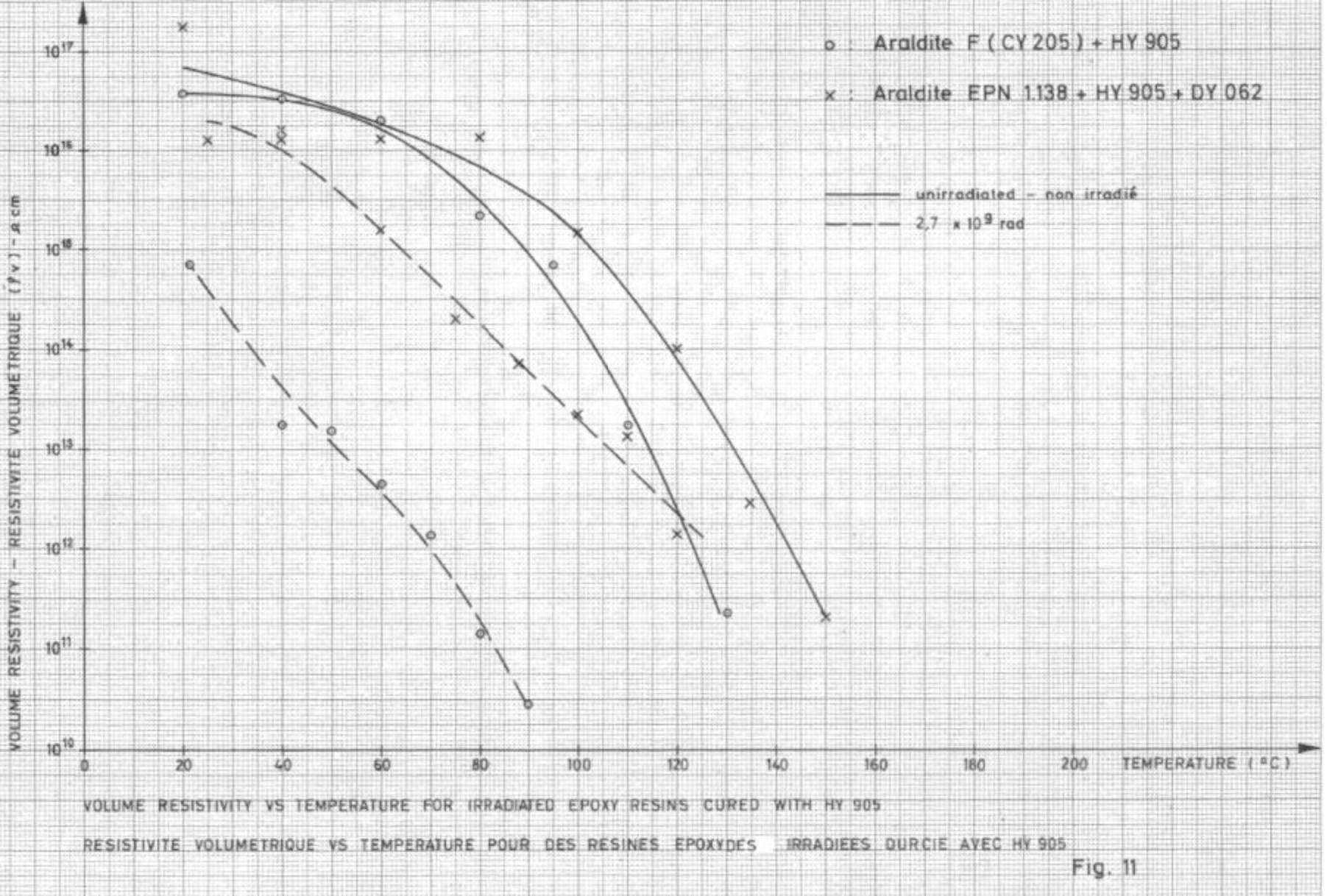
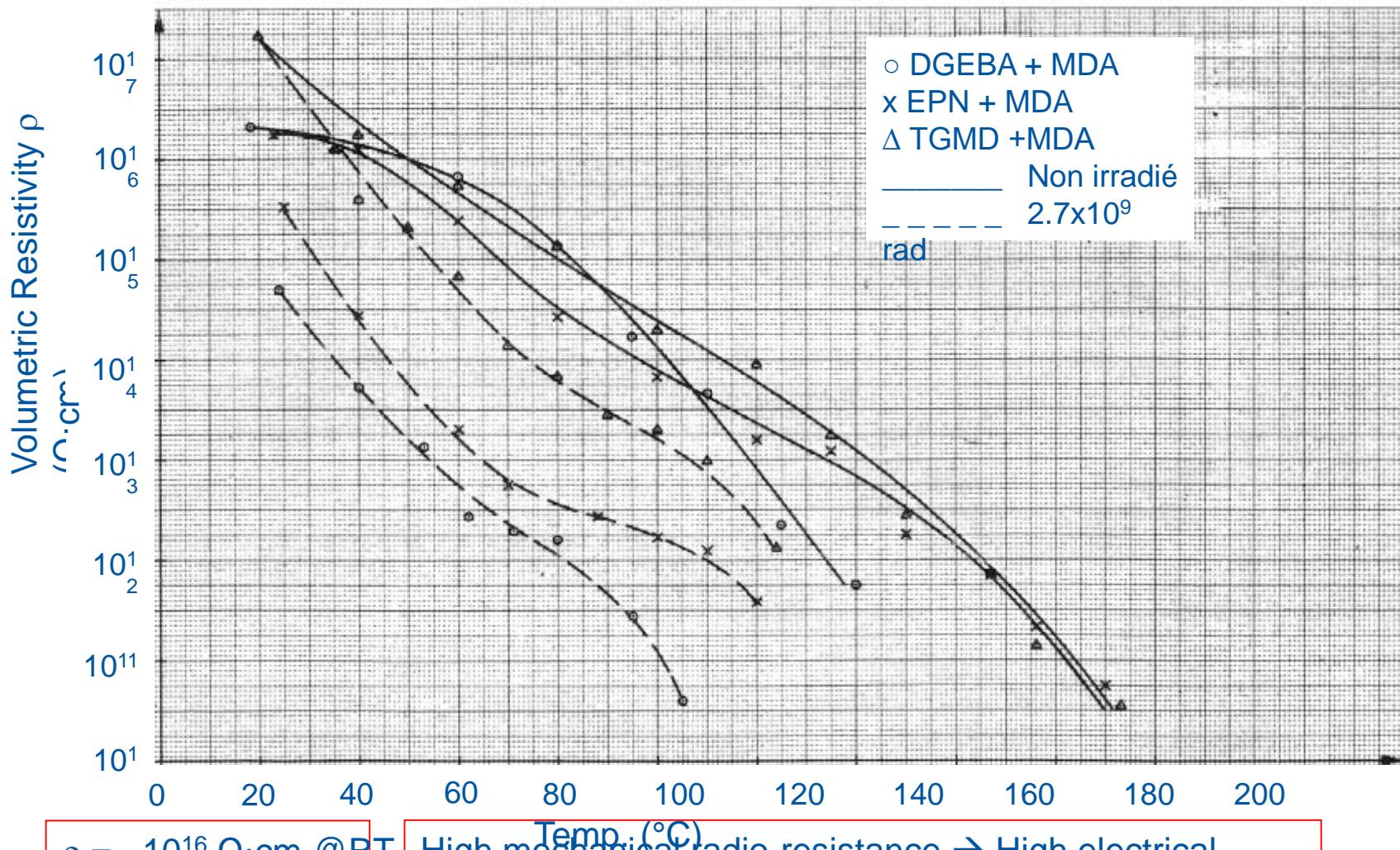


Fig. 11

Electrical Properties Changes 2



DGEBA considerations

4.1 Pure resin combinations (Table 2 and Figs. 1 to 6)

The radiation resistance of composite insulating materials depends primarily on the binding material, in particular in cases where the other components are inorganic, e.g. glass tape, mica, etc. For this reason pure resins that are generally used as binding materials were included in this study. On the other hand, not too much importance should be attributed to these results since the radiation resistance may be considerably improved by the reinforcing materials.

Comparing the results and taking the half-value dose for flexural strength after irradiation as the parameter, the following radiation resistance was found:

- No. 338, epoxy resin + isocyanate up to 1×10^8 Gy
- No. 348, epoxy resin: DGEBA + anhydride + other components up to 3×10^7 Gy
- No. 336, epoxy resin: DGEBA + anhydride + other components up to 1×10^7 Gy
- No. 337, silicone resin up to 1×10^7 Gy
- No. 369, silicone resin up to 1×10^7 Gy
- No. 368, epoxy resin: DGEBA + anhydride + other components up to 3×10^6 Gy

4

No.	Material Type Supplier Remarks	Dose (Gy)	Flex. strength	Deflexion	Modulus of	RI IEC 544-4 at 10^5 Gy/h
			at max. load S (MPa)	at max. load D (mm)	elasticity M (GPa)	
336	Solventless epoxy resin (Base: DGEBA + anhydride hardener + other components)	0.0	85.0 ± 3.0	4.6 ± 0.1	3.36 ± 0.02	7.3
	Micadur resin	3.0×10^5	90.6 ± 7.5	4.6 ± 0.1	3.54 ± 0.09	
	BBC, Baden	1.0×10^6	94.4 ± 6.0	5.2 ± 0.3	3.47 ± 0.11	
	HV machine insulation applica- tion	3.0×10^6	84.2 ± 6.0	4.6 ± 0.6	3.41 ± 0.16	
		1.0×10^7	75.0 ± 6.1	4.0 ± 0.4	3.46 ± 0.06	
		<u>3.0×10^7</u>	<u>31.4 ± 0.0</u>	<u>2.9 ± 0.0</u>	<u>1.93 ± 0.0</u>	
		1.0×10^8	6.4 ± 2.5	0.8 ± 0.3	1.00 ± 0.32	