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The magnetic field dependent gradient effect and its correction in reference and relative dosimetry

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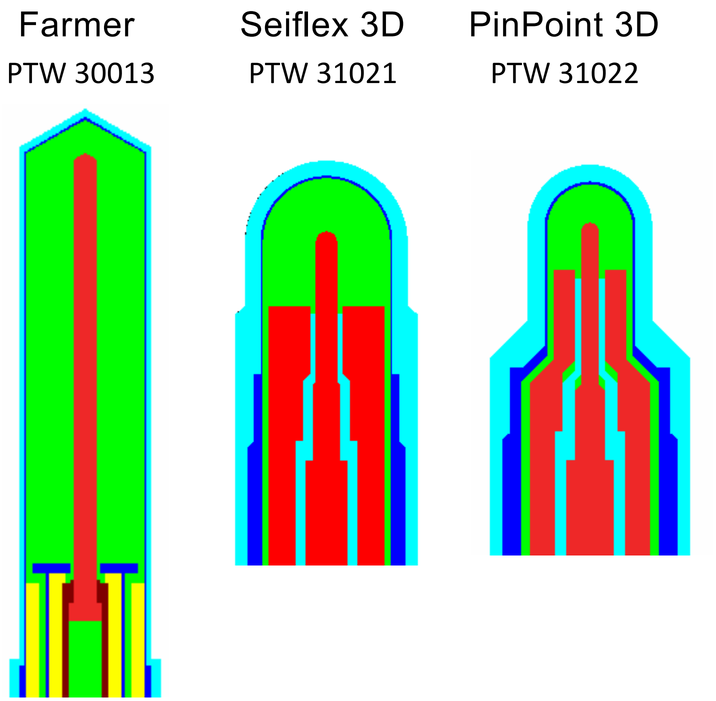
Motivation

Does the EPOM along the depth axis change in a magnetic field?

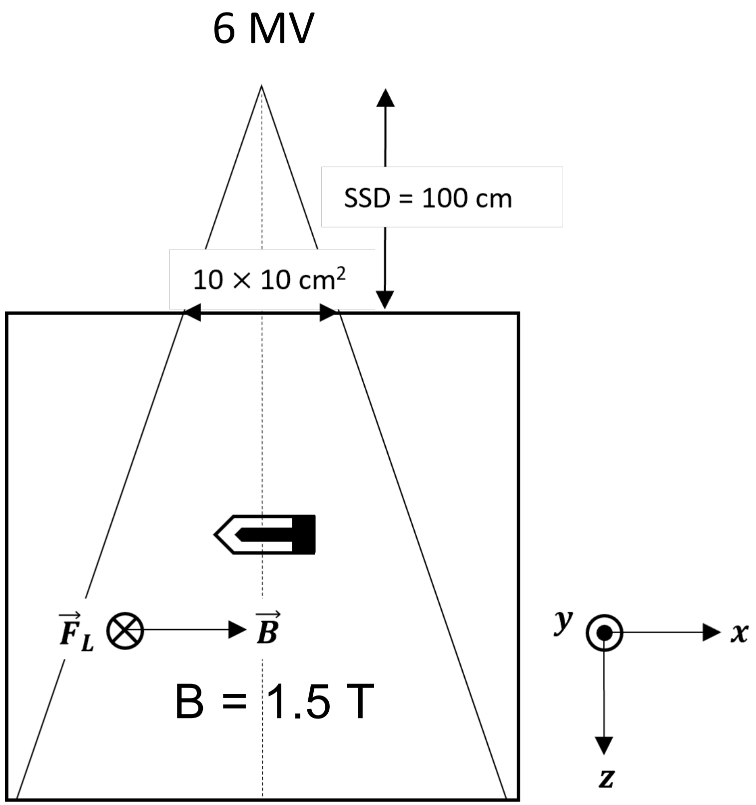
- Magnetic field and the depth dependence of chamber's perturbation correction factors, including the gradient (displacement) correction factor P_{gr}
- The effective point of measurement $\mathcal{P}_{\mathrm{eff}}$ in a magnetic field
- Field-size dependence of $\mathcal{P}_{\mathrm{eff}}$
- Clinical recommendations for corrections in reference and relative dosimetry

Tekin T, Blum I, Delfs B, Schönfeld AB, Poppe B, Looe HK. The magnetic field dependent displacement effect and its correction in reference and relative dosimetry. Phys Med Biol. 2022 Feb 9;67(4).

Simulation setup

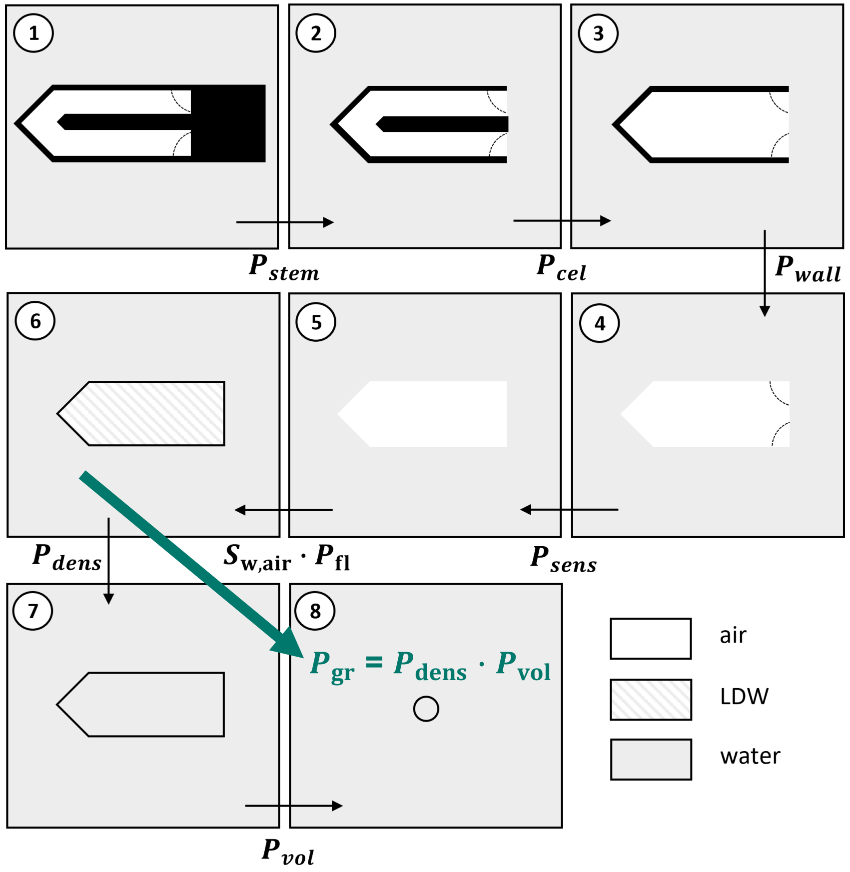


EGSnrc 2019a, user code *egs_chamber* with *eemf-macro* (EM ESTEPE = 0.2)

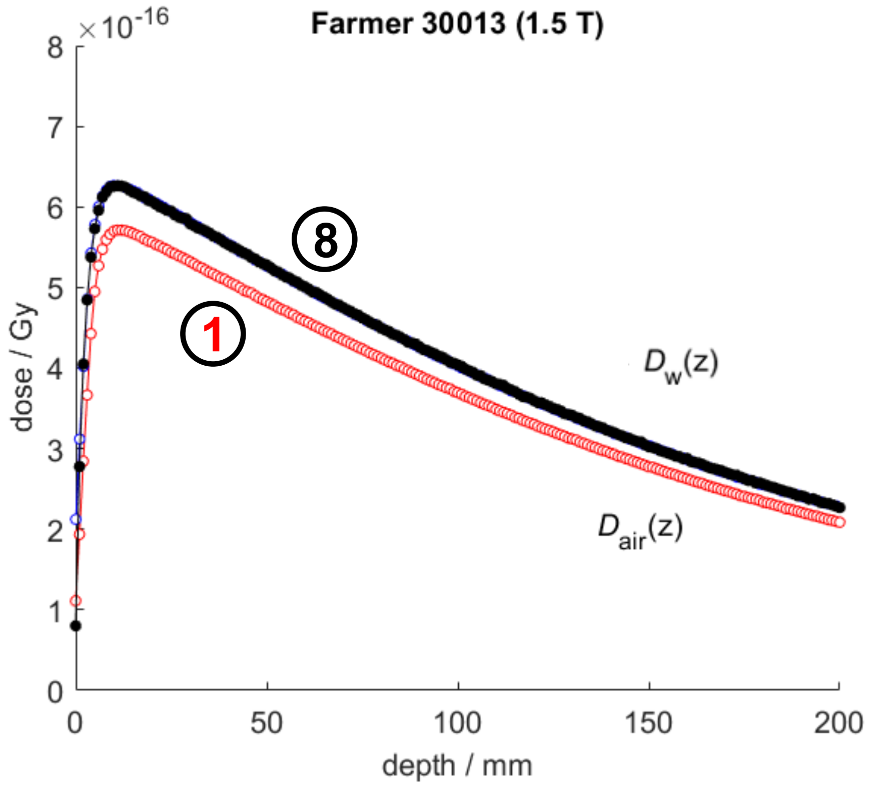


Not to scale

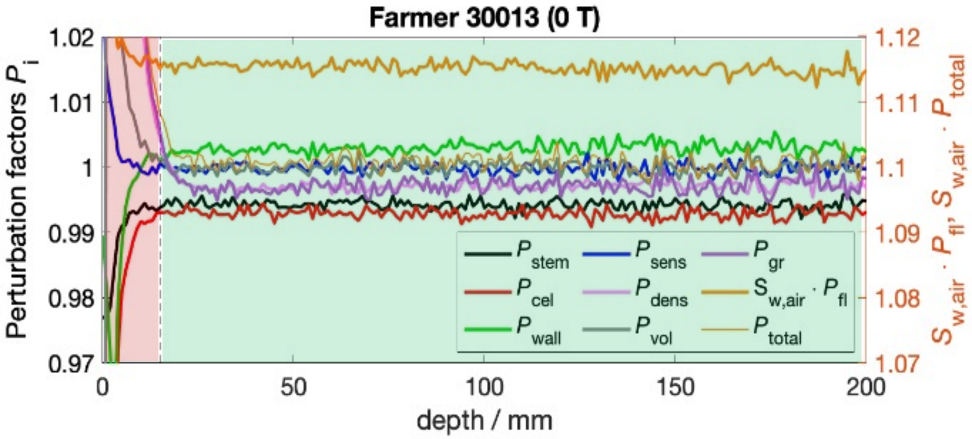
Perturbation correction factors

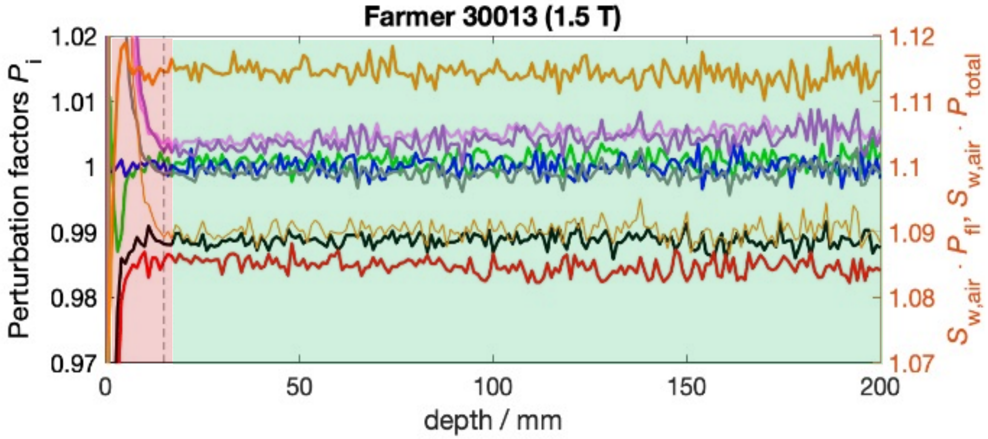


For each model, a depth dose curve was simulated along the beam axis.



Perturbation correction factors





depth dependence

constant within the uncertainty (+/- 0.1%).

magnetic field dependence i.e. the influence of detector components → $k_B \neq 1$

Tekin T, Blum I, Delfs B, Schönfeld AB, Poppe B, Looe HK. The magnetic field dependent displacement effect and its correction in reference and relative dosimetry. Phys Med Biol. 2022 Feb 9;67(4).

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Perturbation correction factors (refence depth 10 cm)

Chamber	30013			31021			31022		
Magnetic field / T	0	1.5	Δ (%)	0	1.5	Δ (%)	0	1.5	Δ (%)
P_{stem}	0.9945(3)	0.9888(4)	-0.57	0.9810(4)	0.9710(4)	-1.00	0.9827(4)	0.9773(6)	-0.54
P_{wall}	1.0032(3)	1.0012(4)	-0.20	1.0020(4)	1.0011(4)	-0.09	1.0024(4)	1.0010(6)	-0.14
P_{cel}	0.9925(3)	0.9841(4)	-0.84	0.9956(4)	0.9923(4)	-0.33	0.9961(4)	0.9918(6)	-0.43
P_{sens}	0.9995(3)	1.0002(4)	+0.07	1.0004(3)	1.0002(4)	-0.02	1.0027(4)	1.0033(6)	+0.06
$s_{w,air} \cdot P_{fl}$	1.1157(3)	1.1142(4)	-0.15	1.1158(3)	1.1156(4)	-0.02	1.1158(4)	1.1157(5)	-0.01
P_{dens}	0.9971(2)	1.0051(3)	+0.80	0.9972(3)	0.9999(3)	+0.27	0.9981(3)	0.9992(4)	+0.11
P_{vol}	0.9999(6)	1.0011(6)	+0.12	0.9994(6)	1.0006(6)	+0.12	0.9993(6)	1.0012(6)	+0.19
P_{gr}	0.9970(6)	1.0063(7)	+0.93	0.9967(7)	1.0005(7)	+0.38	0.9974(7)	1.0004(7)	+0.30
$s_{w,air} \cdot P_{total}$	1.1008(6)	1.0926(7)	-0.82	1.0889(7)	1.0768(7)	-1.21	1.0947(7)	1.0865(7)	-0.82
$k^{B}_{Q_{msr}}$	0.9926(9)			0.9889(9)			0.9925(9)		

Perturbation correction factors (reference depth 10 cm)

Chamber	30013			31021			31022		
Magnetic field / T	0	1.5	Δ (%)	0	1.5	Δ (%)	0	1.5	Δ (%)
P_{stem}	0.9945(3)	0.9888(4)	-0.57	0.9810(4)	0.9710(4)	-1.00	0.9827(4)	0.9773(6)	-0.54
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P_{vol}	0.9999(6)	1.0011(6)	[illegible]	[illegible]	[illegible]	[illegible]	0.9993(6)	1.0012(6)	+0.19
P_{gr}	0.9970(6)	1.0063(7)	+0.93	0.9967(7)	1.0005(7)	+0.38	0.9974(7)	1.0004(7)	+0.30
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$k^B_{Q_{msr}}$	0.9926(9)			0.9889(9)			0.9925(9)		

$$k^B_{Q_{msr}} = \frac{(S_{w,air} \cdot P_{total})_{1.5\ T}}{(S_{w,air} \cdot P_{total})_{0\ T}}$$

Mean value (De Prez et al 2019): 0.993(3)

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Effective point of measurement $\mathcal{P}_{\text{eff}}$

- The displacement of $\mathcal{P}_{\text{eff}}$ at z_{eff} from the reference point $\mathcal{P}_{\text{ref}}$ at z_{ref} is given by Δz-shift:

$$z_{\text{eff}} = z_{\text{ref}} + \Delta z$$

- Δz-shift is determined by minimizing the variation of the ratio $D_{\text{w}}(z_{\text{ref}} + \Delta z)/\bar{D}_{\text{air}}(z_{\text{ref}})$ with the depth with respect to the proportional constant k and the shift Δz according to the equation (Kawrakow *et al* 2006 and Tessier *et al* 2010):

$$\chi^2_{\min} = \underset{k,\Delta z}{\arg\min} \sum_{z_{\text{ref}}=0.4\text{ cm}}^{z_{\text{ref}}=19.6\text{ cm}} \left[\frac{D_{\text{w}}(z_{\text{ref}} + \Delta z)}{\bar{D}_{\text{air}}(z_{\text{ref}})} - k\right]^2 \Big/ u^2 \left[\frac{D_{\text{w}}(z_{\text{ref}} + z)}{\bar{D}_{\text{air}}(z_{\text{ref}})}\right]$$

Effective point of measurement $\mathcal{P}_{\mathrm{eff}}$

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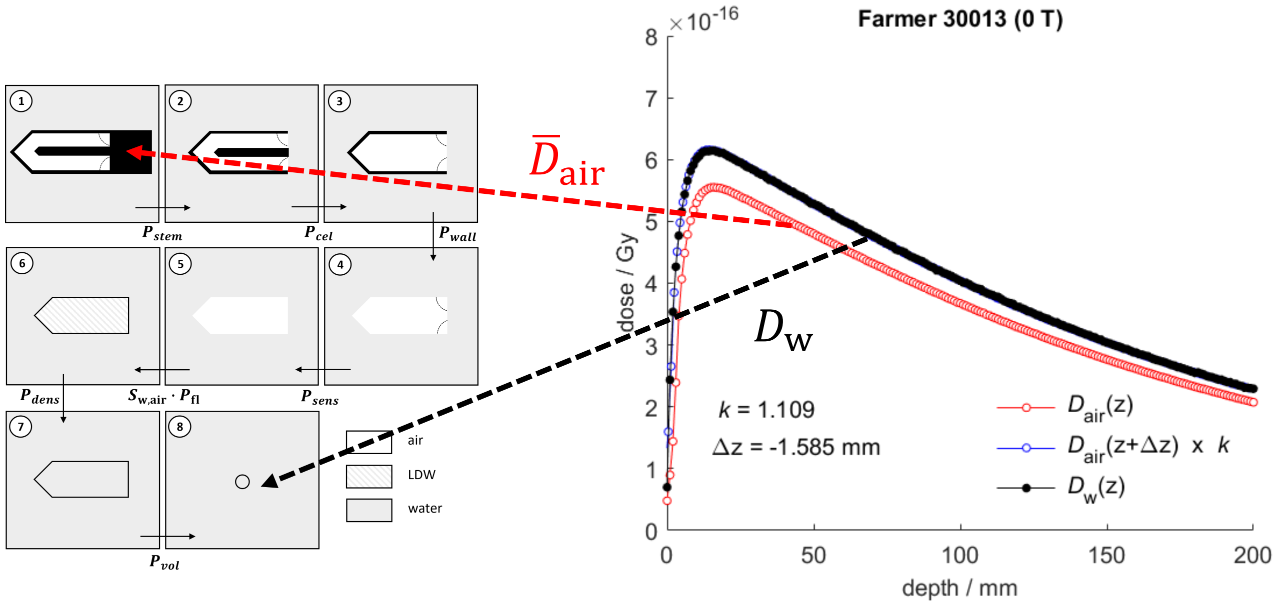
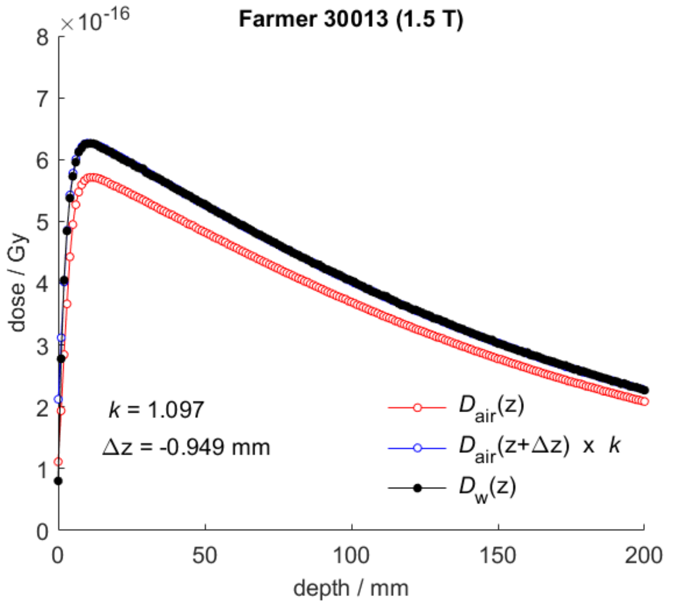
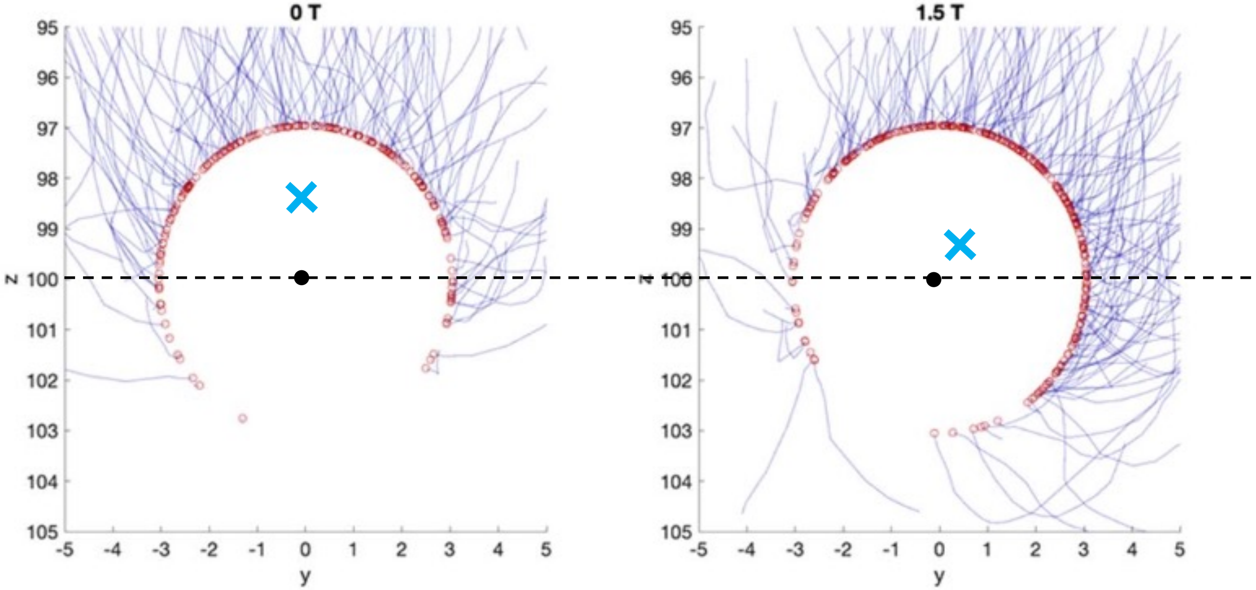




Effective point of measurement $\mathcal{P}_{\mathrm{eff}}$

Ionization chamber	30013		31021		31022	
Magnetic field / T	0	1.5	0	1.5	0	1.5
k	1.110	1.097	1.094	1.079	1.097	1.086
Δz / mm	-1.522(07)	-0.897(09)	-0.833(10)	-0.471(11)	-0.332(10)	-0.196(12)
Δz / r	-0.499(02)	-0.294(03)	-0.347(04)	-0.196(05)	-0.229(07)	-0.135(08)

40% reduction



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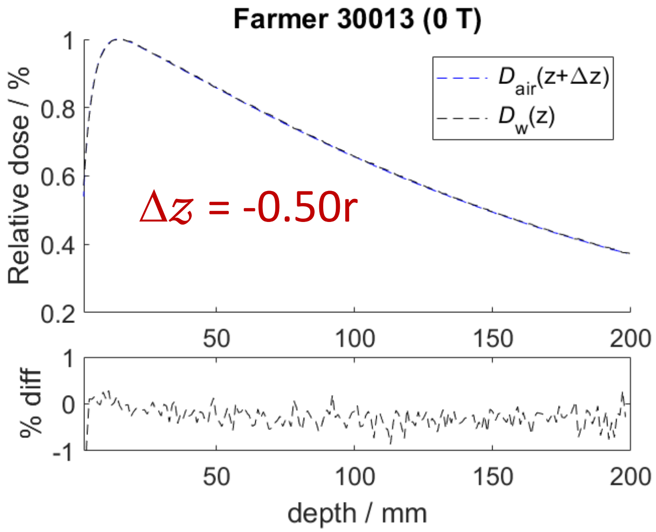

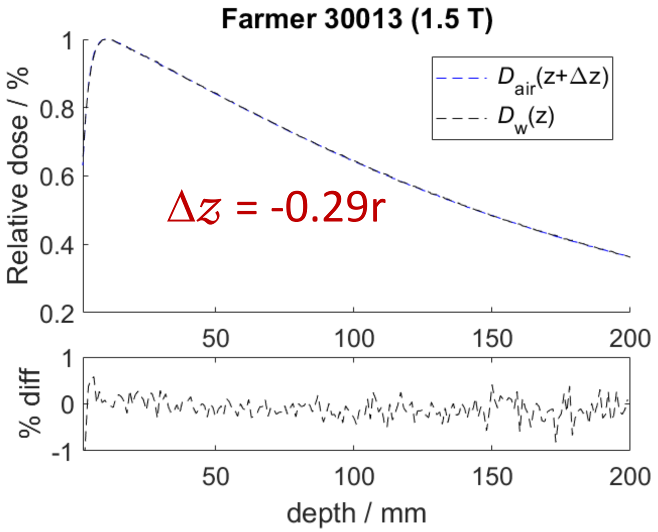

Effective point of measurement $\mathcal{P}_{\mathrm{eff}}$

PinPoint 3D 31022

Field size / cm²	**1 × 1**		**2 × 2**		**10 × 10**	
Magnetic field / T	0	1.5	0	1.5	0	1.5
k	1.110	1.102	1.099	1.090	1.097	1.086
Δz **/ mm**	-0.350(05)	-0.180(07)	-0.344(05)	-0.170(07)	-0.332(10)	-0.196(12)
Δz / $\mathbf{r}$	-0.241(03)	-0.124(05)	-0.237(03)	-0.117(05)	-0.229(07)	-0.135(08)

Δz-shift or $\mathcal{P}_{\mathrm{eff}}$ in a magnetic field can be approximated as field size-independent in relative dosimetry.

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Summary

- The magnetic field correction factor $k^{B}_{Q_{\mathrm{msr}}}$ includes the change of P_{gr} due to the magnetic field
- P_{dens}, which is part of P_{gr}, accounts also for the change of electron trajectories in a magnetic field within the low-density air cavity
- $\mathcal{P}_{\mathrm{eff}}$ accounts not only for the gradient effect, but also accounts for the depth-dependent perturbations of other chamber components
- The shift Δz is reduced by 40% in 1.5 T magnetic field for all investigated chambers
- The shift Δz for the PinPoint chamber can be considered as field-size independent