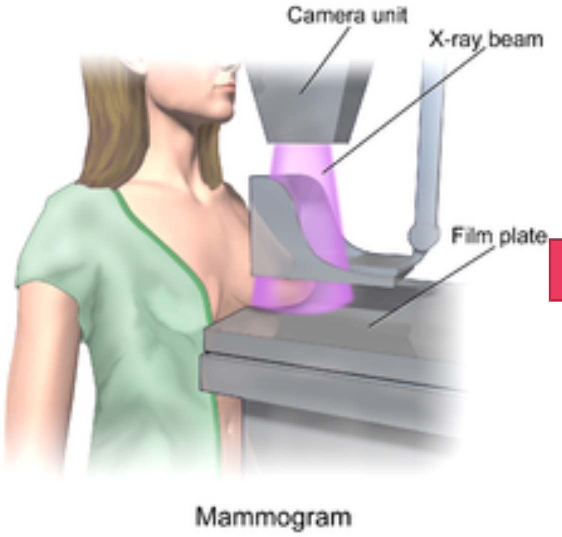
Synchrotron Radiation Breast CT dosimetry

Medical Physics Research Laboratory

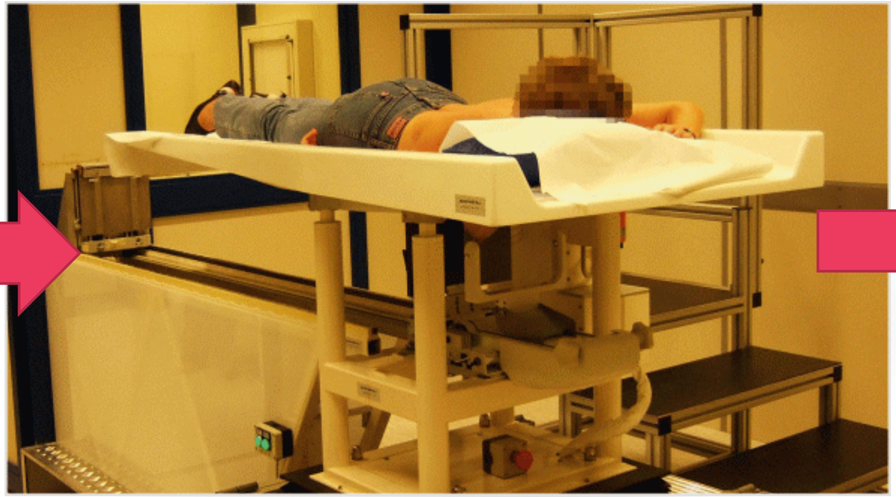
G. Mettivier, A. Sarno, F. Di Lillo and P. Russo

Breast Dosimetry

Mammography



Synchrotron breast CT
Cone Beam Breast CT



Dosimetry ?????

Dance et al, 1980
MGD = cgs K

Boone et al, 2004
MGD = K_{iso} DgN

MGD = ????

2D Dosimetry

2D Breast Dosimetry
Mean Glandular dose

$$D = \frac{E_{dep}}{M}$$

E_{dep} is the energy delivered to the breast tissue (without skin)
M is the breast mass (without skin)

$$MGD = G \times \frac{E_{dep}}{f_g \times M}$$

f_g is the breast glandular fraction by mass
The deposited energy in the breast tissue included the energy released by photons at their interaction site in the breast, as well as the energy released by electrons produced at the photon hit (multiple scatter included).

$$G(E) = \frac{f_g \times \mu_{en}/\rho(E)_g}{f_g \times \mu_{en}/\rho(E)_g + (1-f_g) \times \mu_{en}/\rho(E)_a}$$

The factor G(E), introduced by Boone (1999),
μ_{en}/ρ = the mass energy absorption coefficient.

$$K_{air} = \frac{\sum E_i \times \mu_{en}/\rho(E)_{i,air}}{S}$$

where E_i is the energy of the *i*-th photon which passes through the scoring surface *S*.
No backscatter from the breast is taken into account in the evaluation of K_{air}.

2D Breast Dosimetry
Mean Glandular dose

How to measure

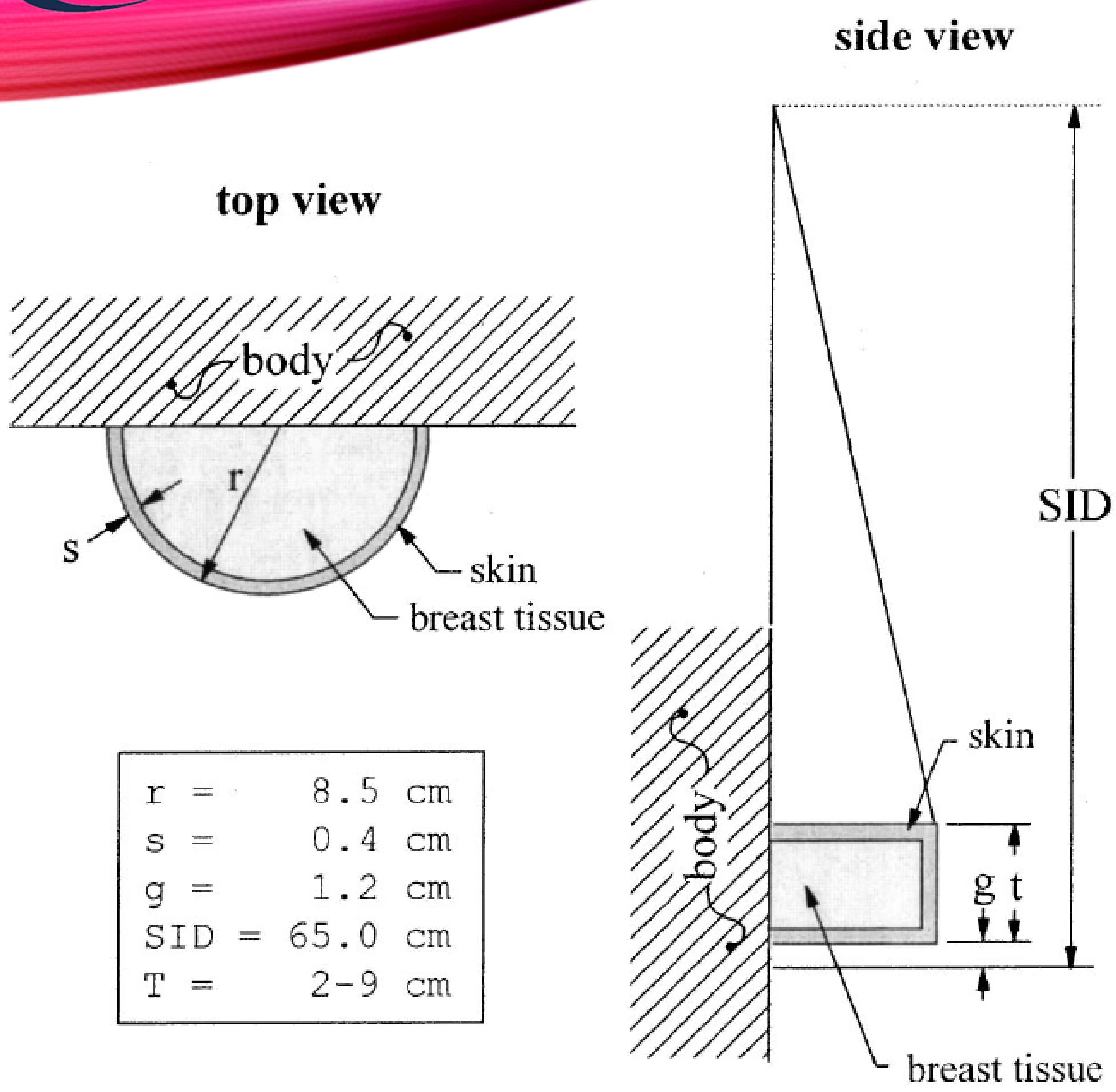
$$MGD = K\ DgN\ (Boone)$$
$$MGD = K\ cgs\ (Dance)$$

- K (mGy) - > Entrance Surface Air Kerma at the skin surface
- D_gN or cgs are coefficients obtained from MC simulations.

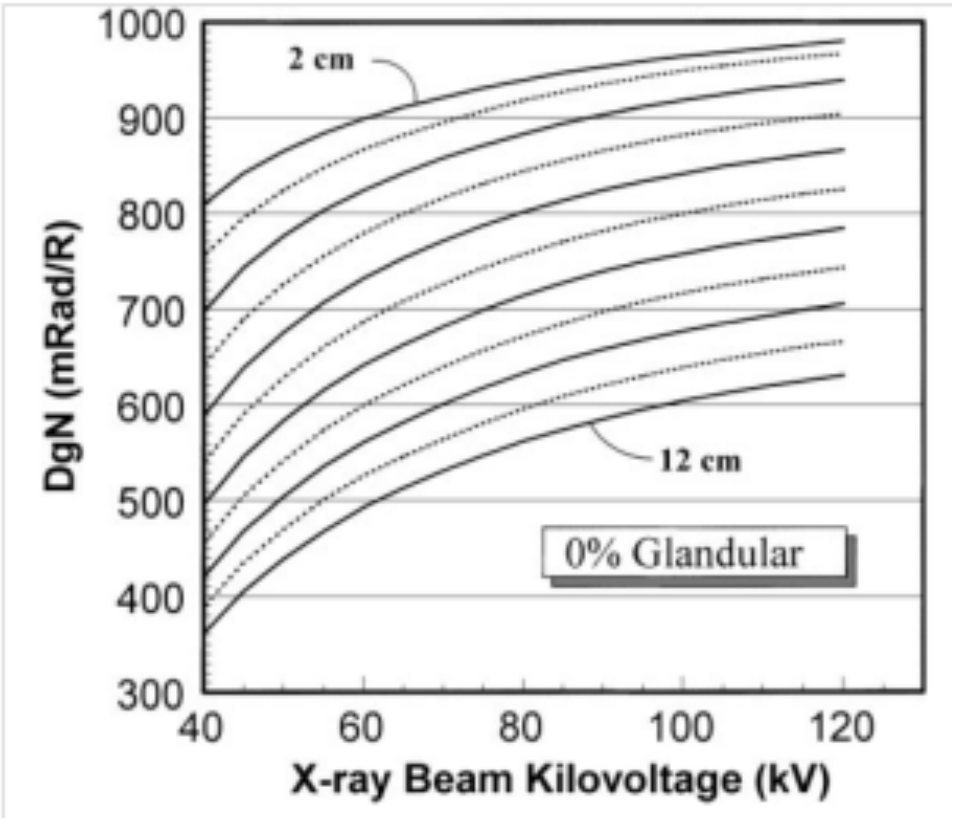
Reference values for a single view for a 50/50, 5.2 cm thick breast
- USA 3 mGy
- Europa 2.5 mGy

D. R. Dance, *Phys. Med. Biol.*, vol. 35, pp. 1211–1219, 1980.
R. van Engen *et al.*, "Addendum on Digital Mammography," European Guidelines for Quality Assurance in Mammography Screening, ch. 3, 1.0 ed. , European Reference Organization for Quality Assured Breast Screening and Diagnostic Services, 2003.

2D Breast Dosimetry
Mean Glandular dose



r =	8.5	cm
s =	0.4	cm
g =	1.2	cm
SID =	65.0	cm
T =	2-9	cm



2D Breast Dosimetry

Mean Glandular dose

Table A5.4: s-factors for clinically used spectra [Dance et al. 2000]

Spectrum	s-factor
Mo/Mo	1.000
Mo/Rh	1.017
Rh/Rh	1.061
Rh/Al	1.044
W/Rh	1.042
W/Al	1.05*

* This value is not given in the paper of [
using the S-values of other spectra.

Table A5.6: c-factors for average breasts for women in age group 50 to 64 (Dance et al. 2000)

Breast Thickness (cm)	c-factors HVL (mm Al)		
	0.30	0.35	0
2	0.885	0.891	0.
3	0.925	0.929	0.
4	1.000	1.000	1.
5	1.086	1.082	1.
6	1.164	1.160	1.
7	1.232	1.225	1.
8	1.275	1.265	1.
9	1.299	1.292	1.
10	1.307	1.298	1.
11	1.306	1.301	1.

Table A5.5: g-factors (mGy/mGy) for breast thicknesses of 2-11 cm and the HVL range 0.30-0.60 mm Al. The g-factors for breast thicknesses of 2-8 cm are taken from Dance (1990), and for 9-11 cm from Dance et al. (2000)

Breast Thickness (cm)	g-factors (mGy/mGy) HVL (mm Al)						
	0.30	0.35	0.40	0.45	0.50	0.55	0.60
2	0.390	0.433	0.473	0.509	0.543	0.573	0.587
3	0.274	0.309	0.342	0.374	0.406	0.437	0.466
4	0.207	0.235	0.261	0.289	0.318	0.346	0.374
4.5	0.183	0.208	0.232	0.258	0.285	0.311	0.339
5	0.164	0.187	0.209	0.232	0.258	0.287	0.310
6	0.135	0.154	0.172	0.192	0.214	0.236	0.261
7	0.114	0.130	0.145	0.163	0.177	0.202	0.224
8	0.098	0.112	0.126	0.140	0.154	0.175	0.195

From 2D Dosimetry to 3D Dosimetry

Cone Beam BCT dosimetry

$$MGD = K_{iso}\, DgN_{CT} \quad (Boone)$$

- K_{iso} (mGy) = Kerma measured at the scanner isocenter
- DgN_{CT} obtained from MC simulations.

- There are no legal reference. The dose reference value is the dose of two view mammography
- Many authors provided DgN_{CT} coefficients both for monochromatic and polychromatic spectra (Boone et al 2004, Thacker and Glick 2004, Sechopoulos et al 2010). Sechopoulos et al (2010) tabulated the DgN_{CT} coefficients for the FDA approved and CE marked Koning corp prototype (http://koninghealth.com/);

Cone Beam BCT dosimetry

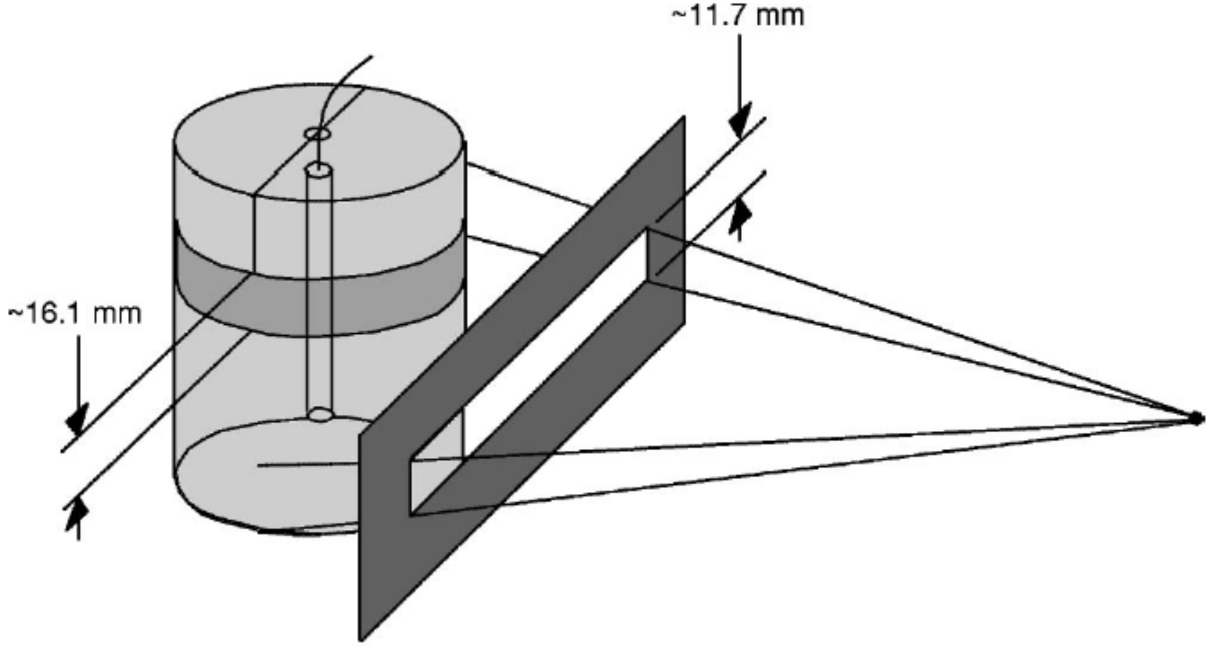
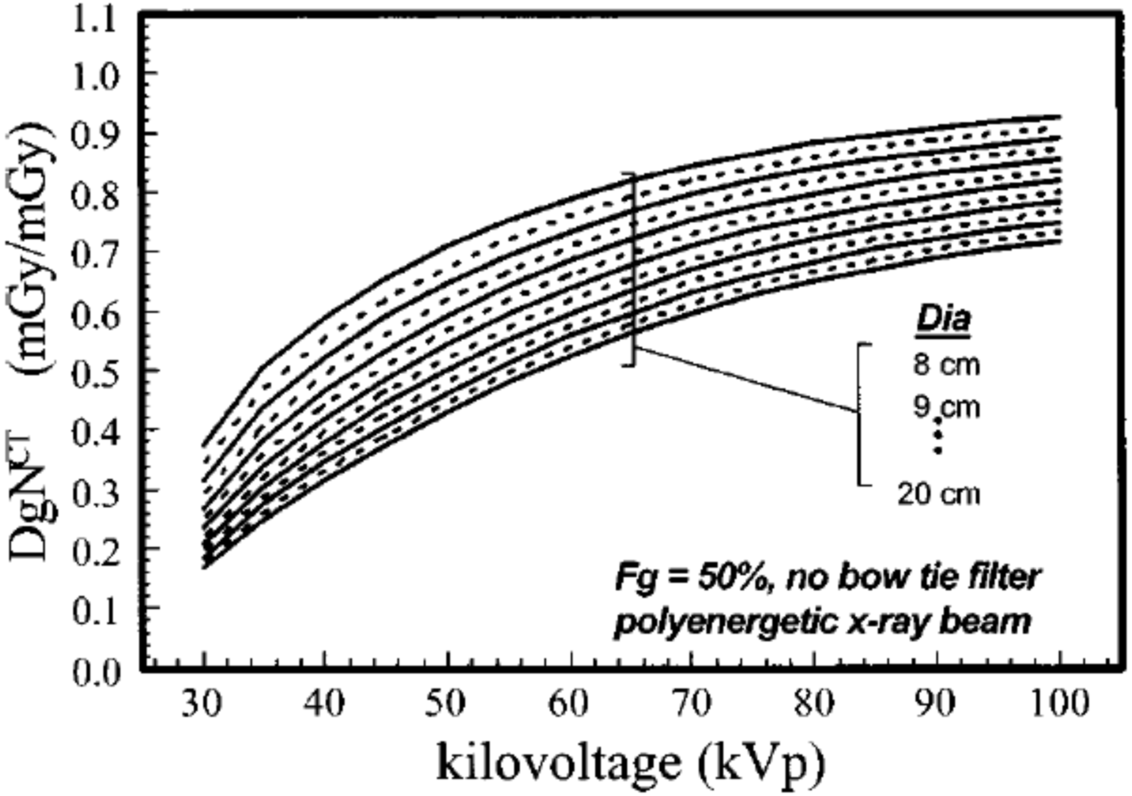


FIG. 1. Geometry for the physical dose measurements made on the prototype breast CT scanner.



J. M. Boone et al., Med. Phys. 31 (2004) 226–235
S.C.Thacker and S.J.Glick, Phys. Med. Biol. 2004, 49: 5433–5444

From 3D Dosimetry
to 3D Syncrotron Dosimetry

Syncrotron Radiation-BCT
Geometry

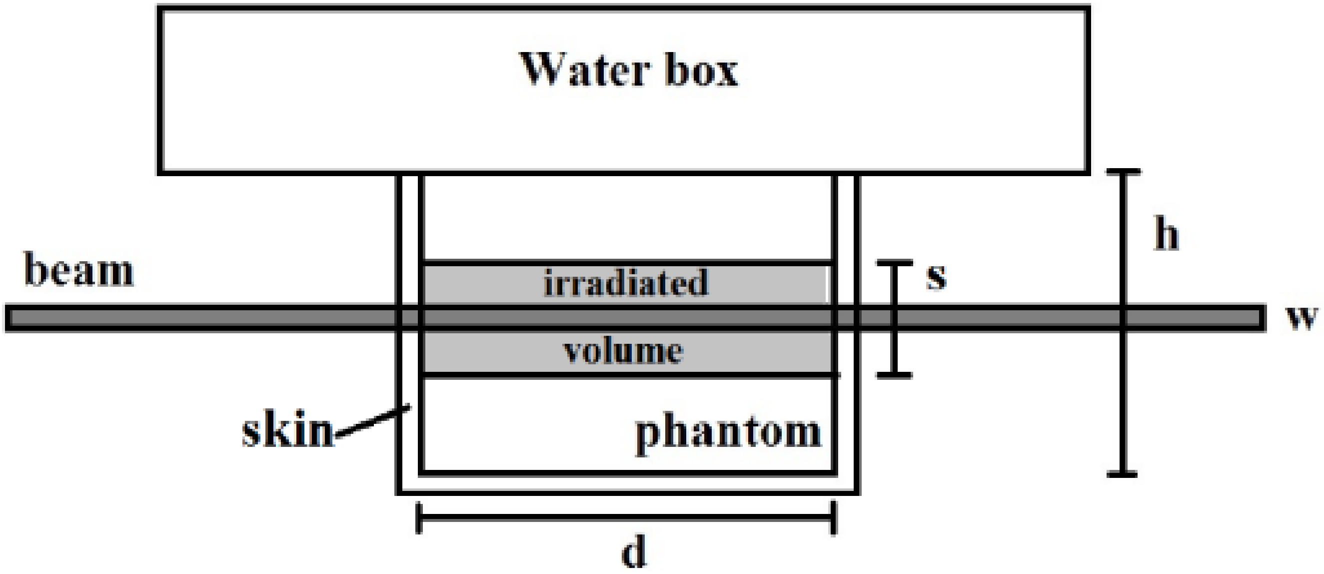
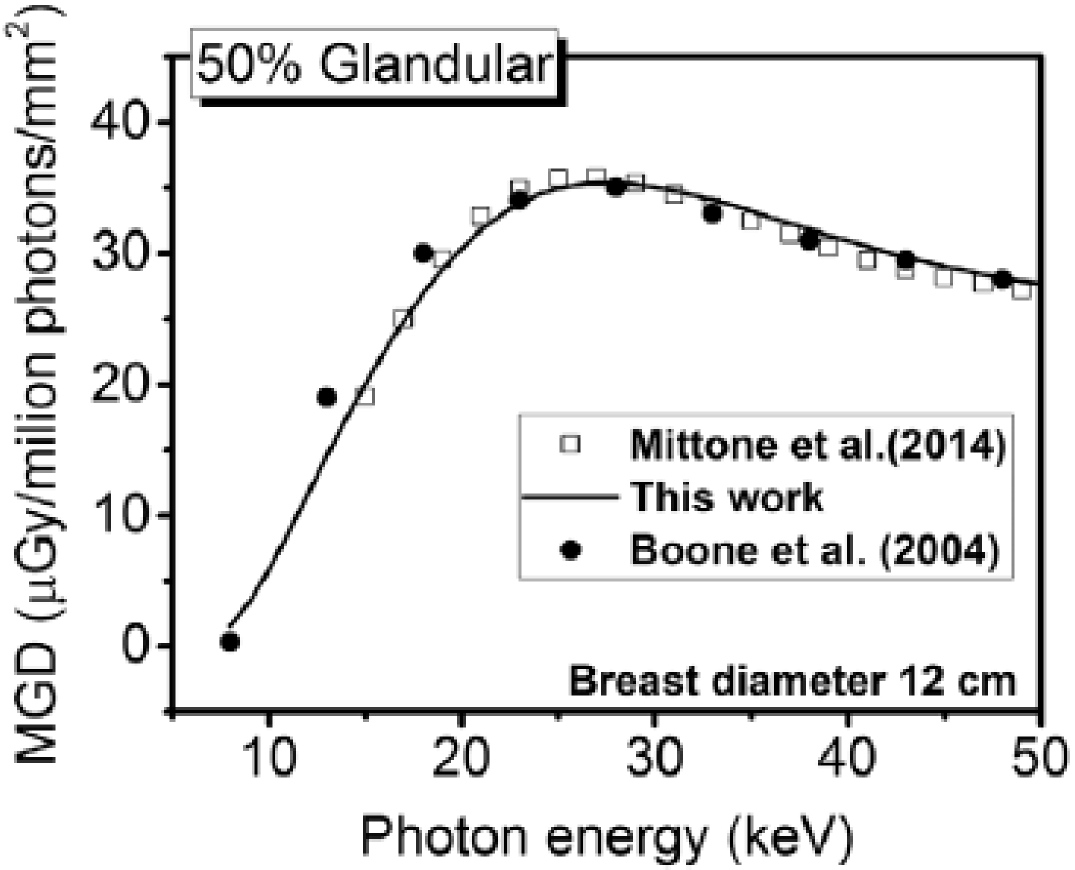


Fig. 3.9. Sketch of the simulated setup. The radiation field shape was set with a fixed width of 150 mm and a variable dimension w according to the case study. The samples had a cylindrical shape with a diameter d and a height h. The dimensions of the irradiated volume are $\pi(d/2)^2 \times s$ where s is variable according to the case studied. A water box (with a volume of 13.5 dm^3) was added for simulating the body of the patient. The skin thickness was 1.45 mm.

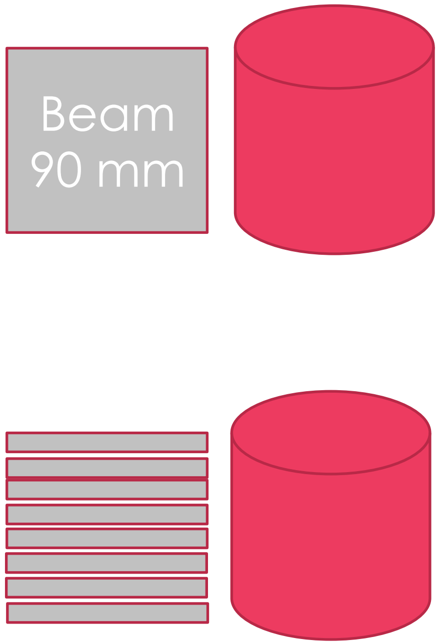
Mettivier et al., PMB 61 (2016) 569-587

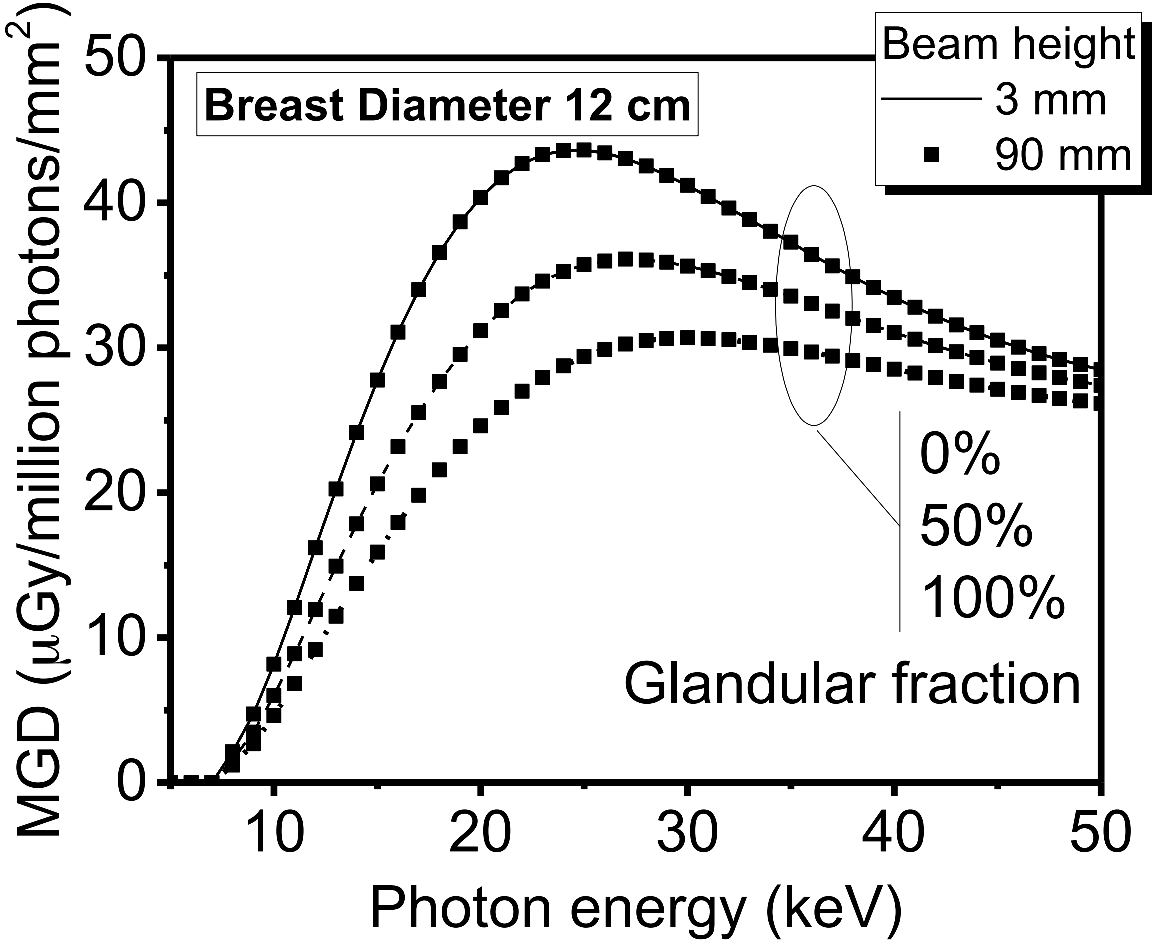
Syncrotron Radiation-BCT
Code validation



Mettivier et al., PMB 61 (2016) 569-587

Syncrotron Radiation-BCT
Dose evaluation



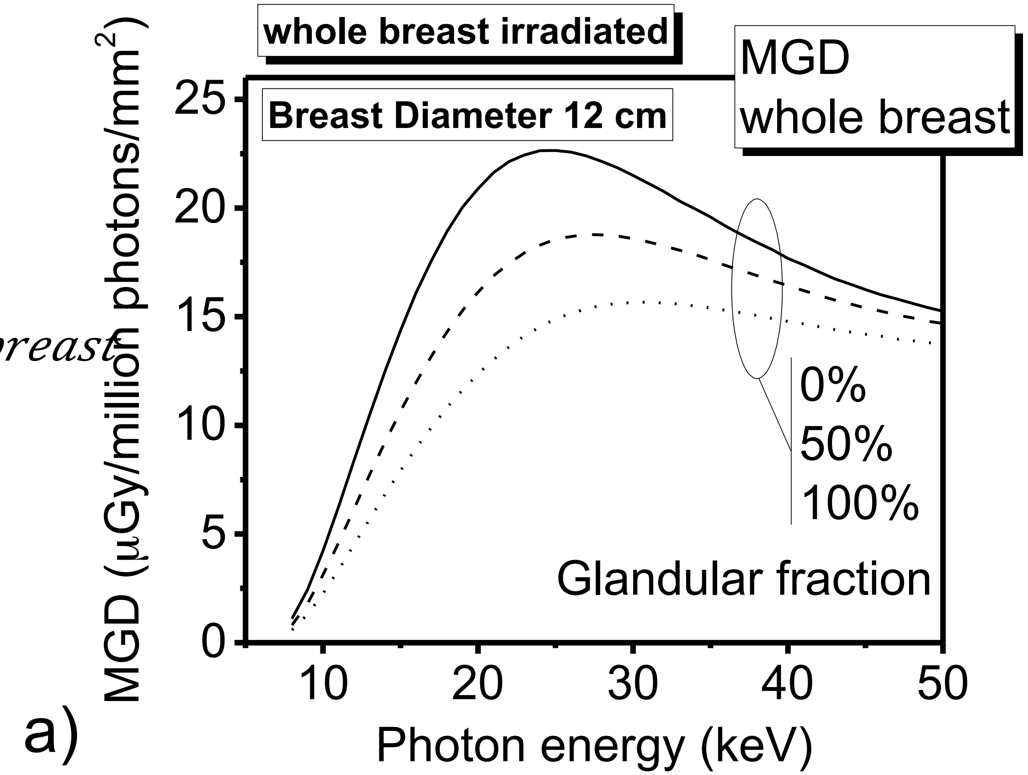


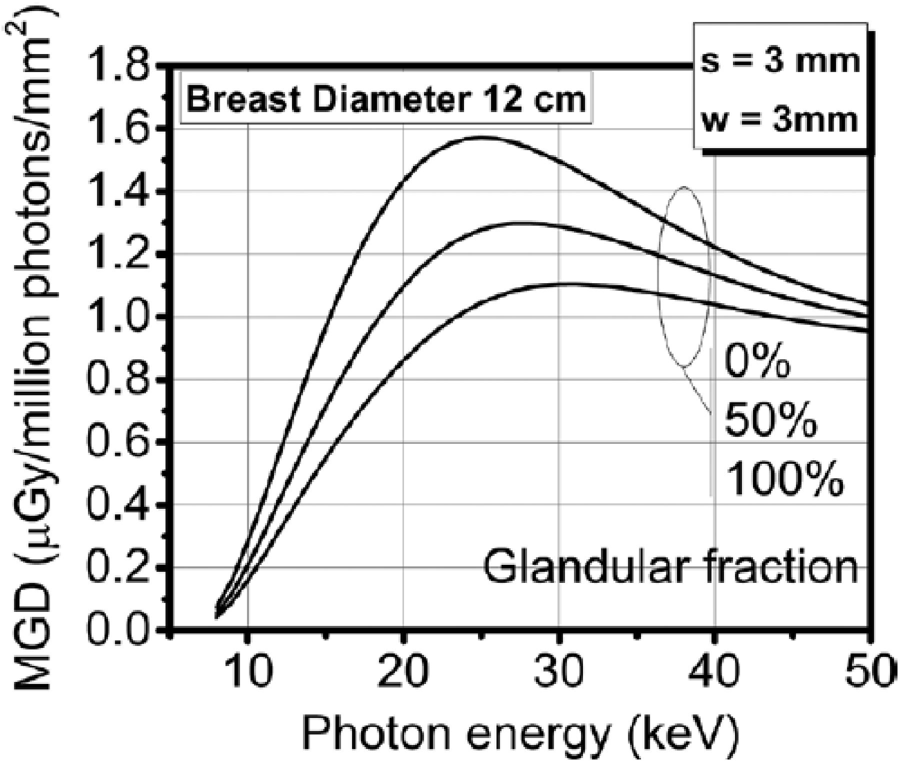
$$MGD = Edep/Mbreast$$

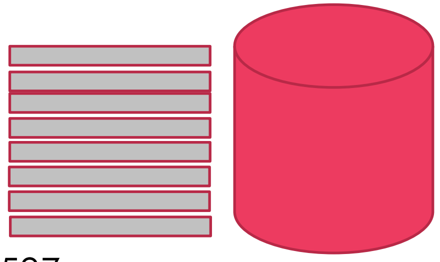
Mettivier et al., PMB 61 (2016) 569-587

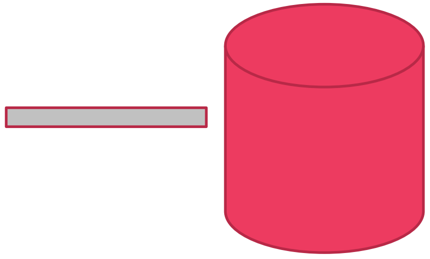
Syncrotron Radiation-BCT
Dose evaluation

$MGD = Edep/Mbreast$



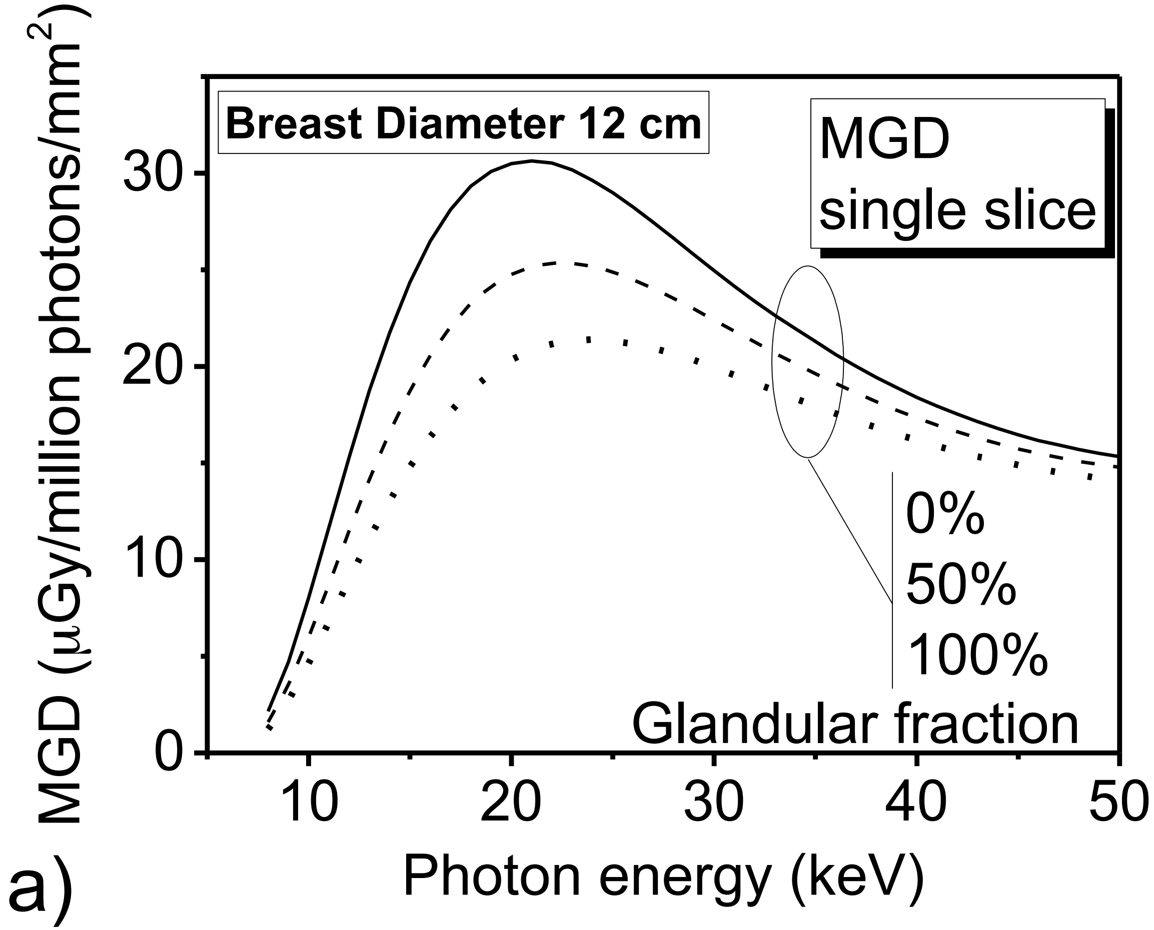


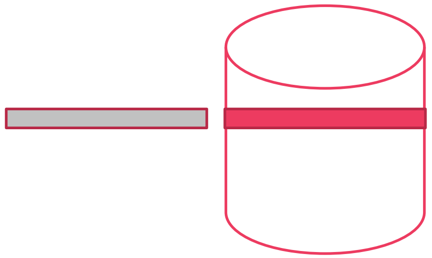




Mettivier et al., PMB 61 (2016) 569-587

Syncrotron Radiation-BCT
Dose evaluation





$MGDv = edep/mirr$

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Syncrotron Radiation-BCT

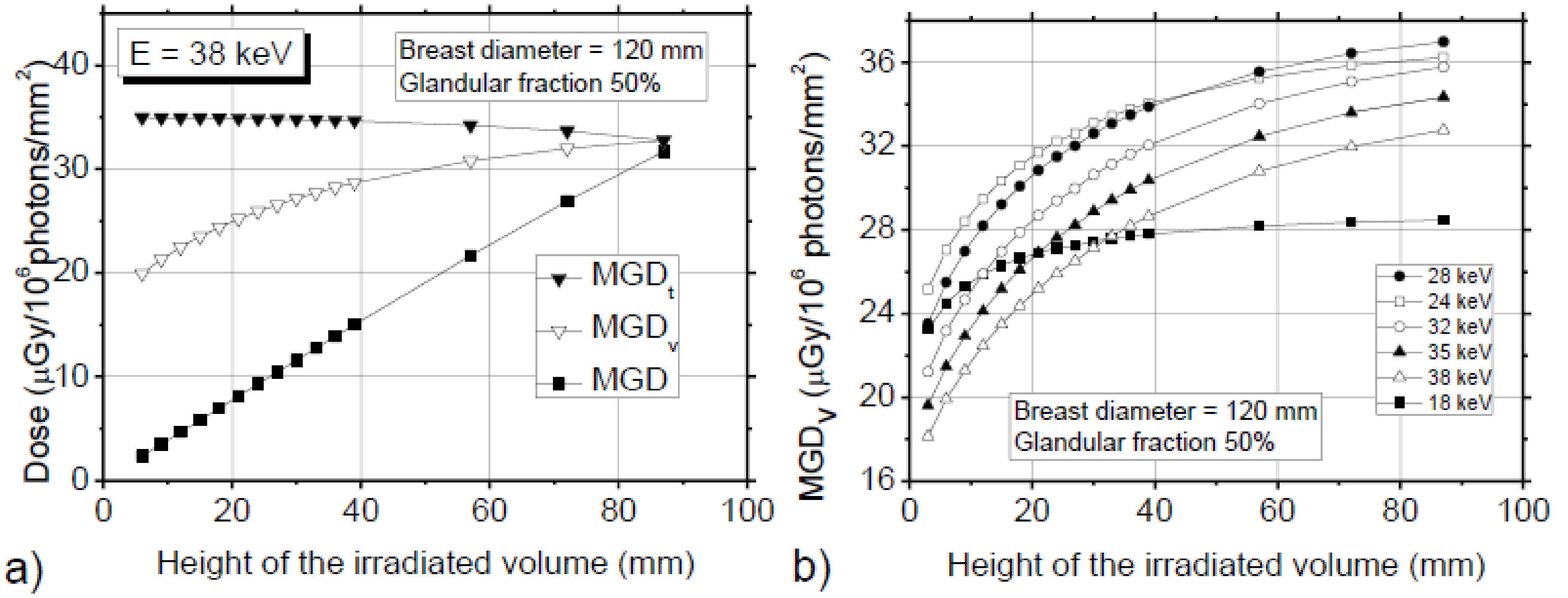

Fig. 3.10. a) The MGD to the glandular mass present in the whole breast (solid square), or in the irradiated volume (open down triangle) or in the irradiated volume adding the contribution from scatter dose (close down triangle) for a 12-cm diameter breast phantom with a glandular fraction of 50% varying the dimension of the irradiated volume with a 3 mm-height beam. The photon energy of the monoenergetic beam was 38 keV. b) MGDv as a function of the height of the irradiated volume at different values of the photon energy.

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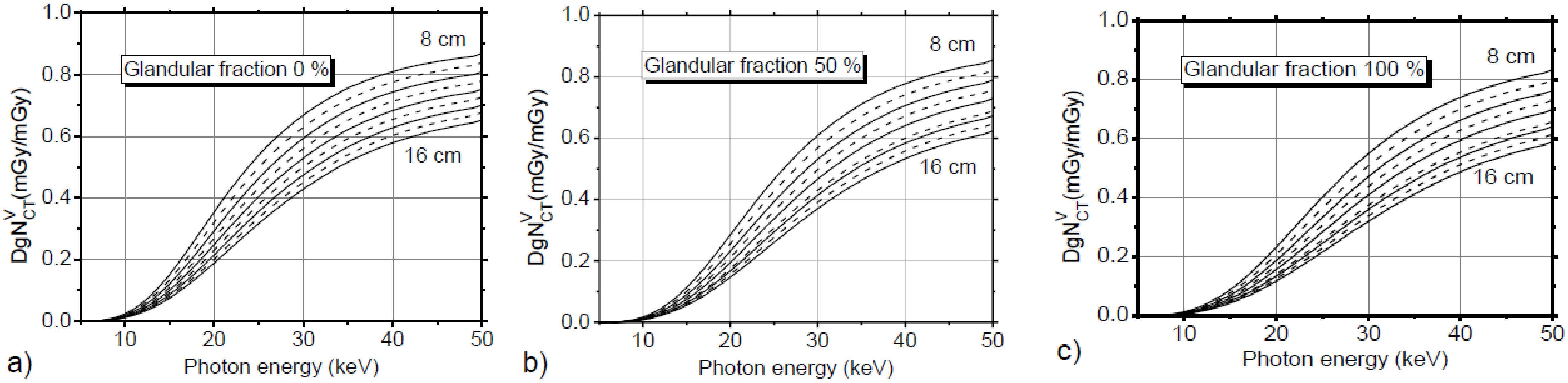
Syncrotron Radiation-BCT



$$MGD_v = K_{iso} \times DgN_{CT}^{v}$$

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What next ?

Code Validation

The MC code was validated as suggested in AAPM TG-195.

MAMMOGRAPHY

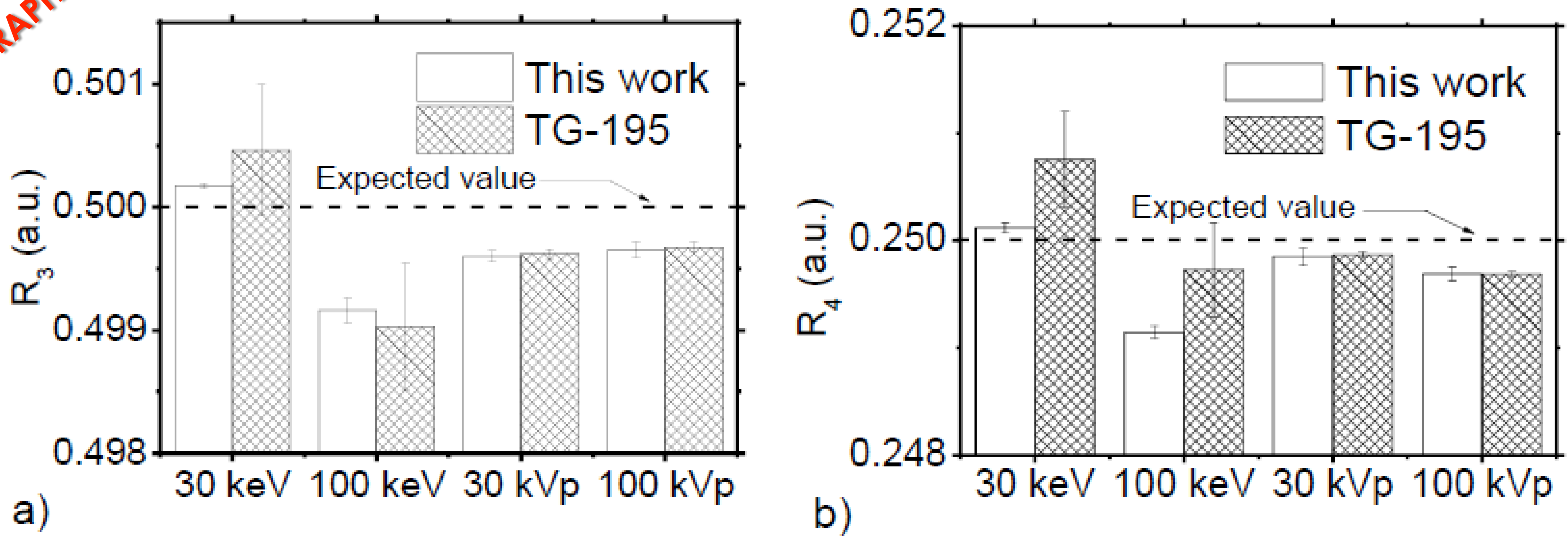

Fig. A1: Air kerma ratio for (a) HVL and (b) QVL Al layers. Results were obtained our MC code and that adopted in AAPM TG report 195.

Sarno et al., PMB 62 (2017) 306-325.

Skin thickness influence

MAMMOGRAPHY

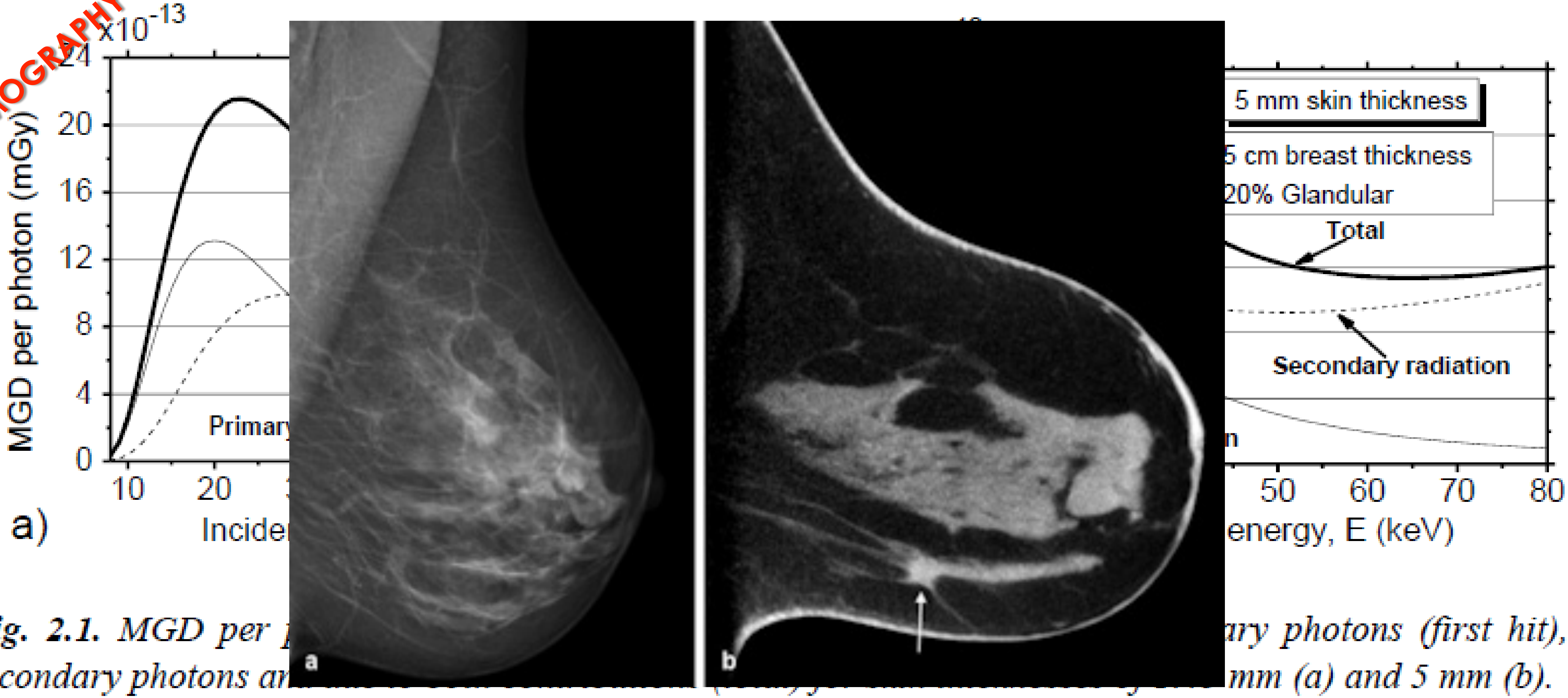

Fig. 2.1. MGD per … *ary photons (first hit), to secondary photons a*… *mm (a) and 5 mm (b).*

Sarno et al., PMB 62 (2017) 306-325.

Skin thickness influence

MAMMOGRAPHY

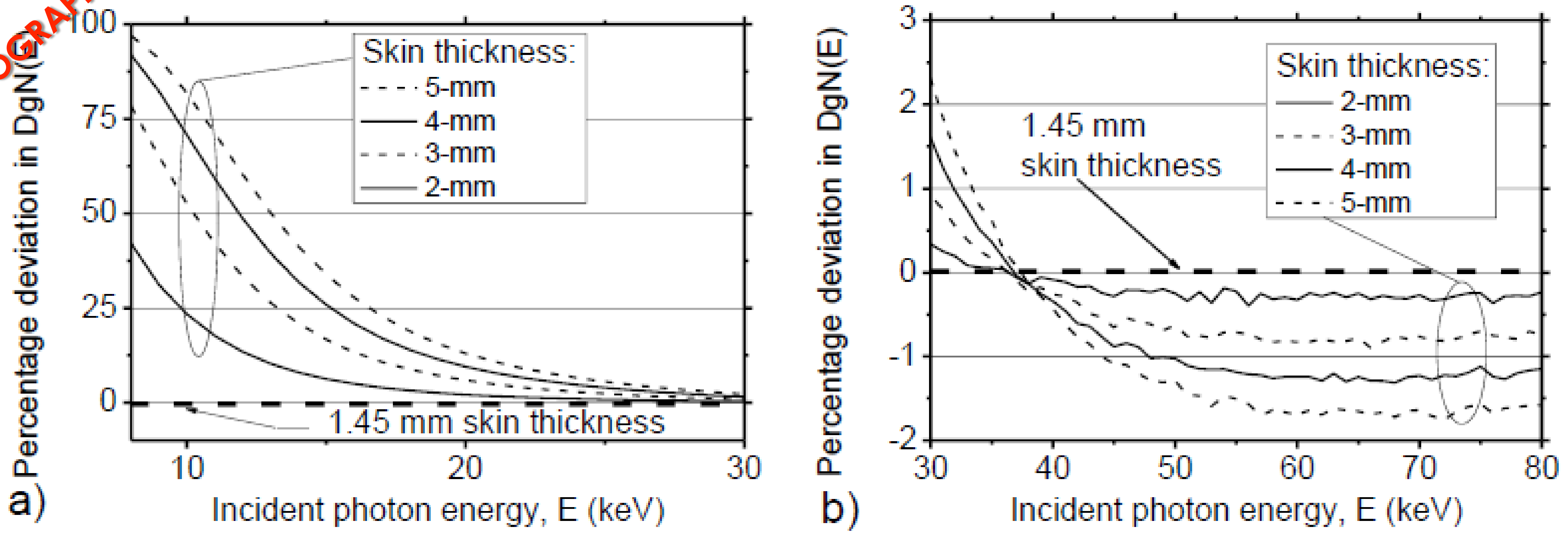

Fig. 2.3. Percentage DgN deviation in the energy range 8–30 keV in panel (a) and in the range 30–80 keV in panel (b), for a breast with skin layer of 5 mm, 4 mm, 3 mm and 2 mm, with respect to that with a skin layer of 1.45 mm thickness. Glandular fraction = 20%; compressed breast thickness = 5 cm.

Sarno et al., PMB 62 (2017) 306-325.

Not homogeneous phantom

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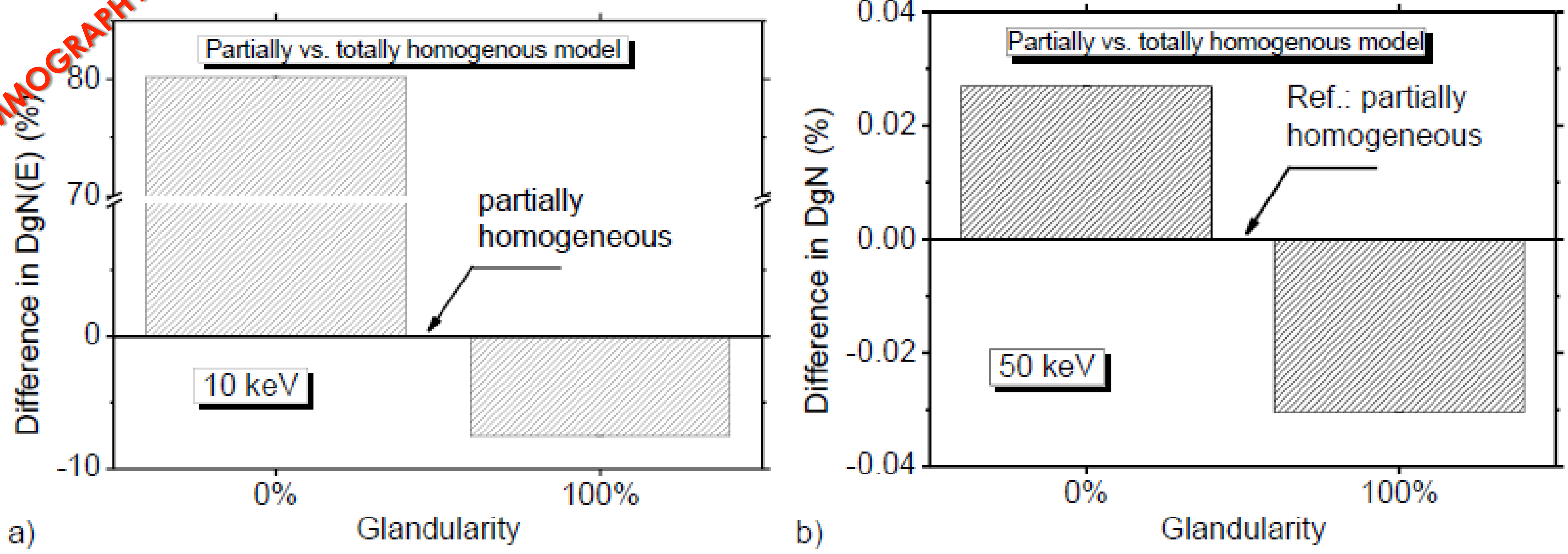

Fig. 2.6. Percentage difference of the totally homogeneous model with respect to the partially homogeneous model at (a) 10 keV and (b) 50 keV, for a breast thickness of 5 cm and glandular fraction of 0% and 100%.

Sarno et al., PMB 62 (2017) 306-325.

Bremsstrahlung

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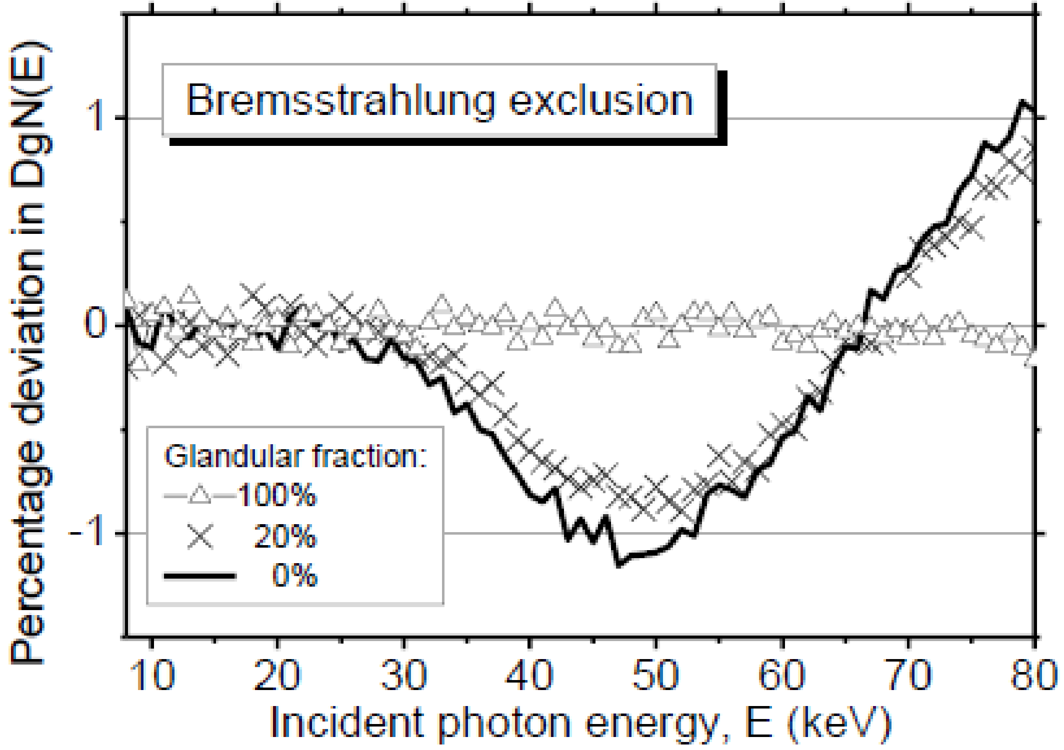

Fig. 2.9. Percentage deviation in DgN(E) from the case in which bremsstrahlung processes are simulated and a low cutoff electron energy is set, for the cases in which the bremsstrahlung processes are not included in the MC simulations. Breast thickness = 5 cm; compression paddles = 2 mm PMMA; skin thickness = 1.45 mm.

Sarno et al., PMB 62 (2017) 306-325.

X-ray incidence angle

MAMMOGRAPHY

$$K_{\text{air}} = \sum_i \frac{E_i \times \frac{\mu_{\text{en}}}{\rho}(E_i)_{\text{air}}}{S},$$

$$K_{\text{air}} = \sum_i \frac{E_i \times \frac{\mu_{\text{en}}}{\rho}(E_i)_{\text{air}}}{S \times \cos\theta_i},$$

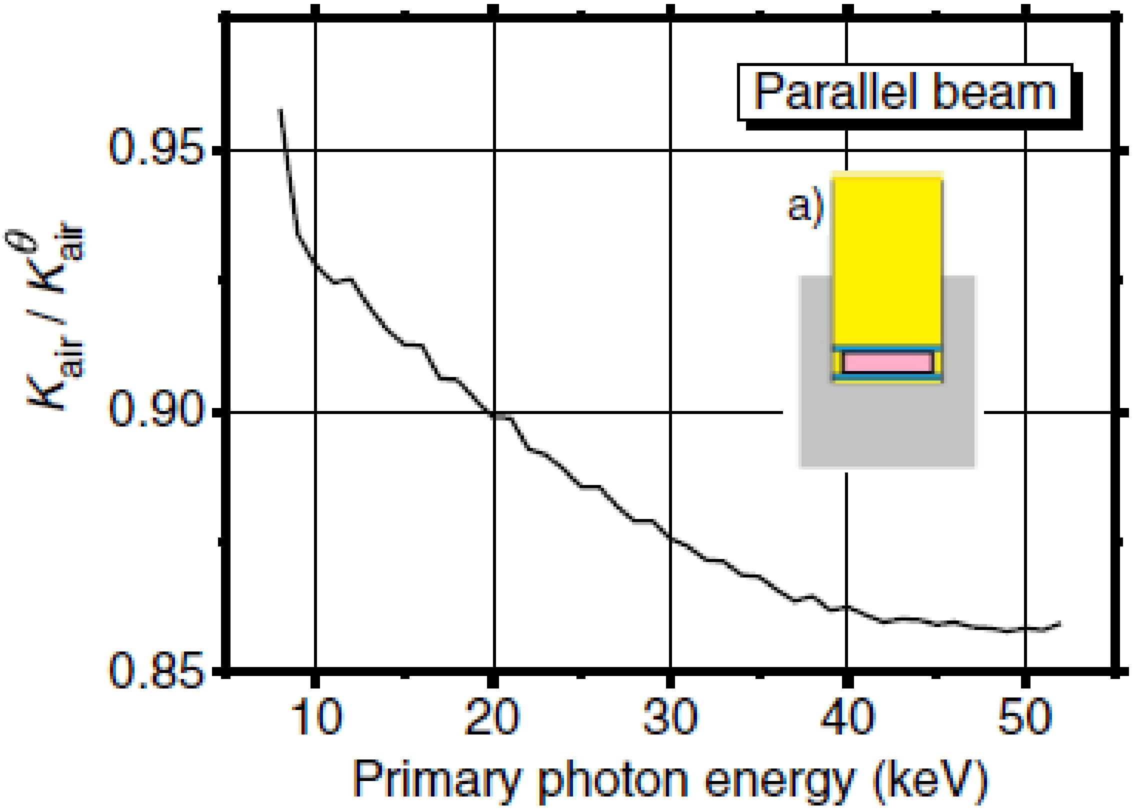

Figure 2. The ratio between the incident air kerma values evaluated with equations (1) and (2), respectively, as a function of photon energy. Parallel beam geometry, source to scoring surface distance = 595 mm, compression paddle thickness = 2 mm. The inset refers to geometry (a) in figure 1.

Sarno et al., PMB 62 (2017) N337-N349.

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Thank you

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