**MEAN GLANDULAR DOSE CONVERSION FACTORS**

The estimation of breast dose for patient exposures and using exposures of PMMA phantoms to simulate the breast is a standard part of mammographic quality control.

In the UK, European and IAEA protocols for dosimetry of standard 2D mammography, use is made of conversion factors calculated by Dance and colleagues (Dance 1990; Dance et al 2000, 2009).

More recently, the methodology has been extended for estimation of breast dose for digital tomosynthesis (Dance et al, 2011, EUREF 2014) and for contrast enhanced digital mammography (Dance and Young, 2014).

Conversion factors from the above publications for patient dosimetry and for dosimetry using PMMA phantoms for all three types of examination can be downloaded here (**LINK**) (Data are provided with permission from IOP publishing.)

***References***

Dance D R 1990 Monte Carlo calculation of conversion factors for the estimation of mean glandular breast dose. *Phys. Med. Biol*. **35** 1211-1219. (LINK)

Dance D R, Skinner C L, Young K C, Beckett J R and Kotre C J 2000. Additional factors for the estimation of mean glandular breast dose using the UK mammography dosimetry protocol *Phys. Med. Biol.* 45 3225-3240. (LINK)

Dance D R, Young K C and van Engen R E 2009 Further factors for the estimation of mean glandular dose using the United Kingdom, European and IAEA dosimetry protocols. *Phys. Med. Biol* **56** 4361-72 (LINK)

Dance D R, Young K C and van Engen R E 2011 Estimation of mean glandular dose for breast tomosynthesis: factors for use with the UK, European and IAEA dosimetry protocols. *Phys. Med. Biol 54* 453-471 (LINK)

Dance D R, Young K C 2014 Estimation of mean glandular dose for contrast enhanced digital mammography: factors for use with the UK, European and IAEA breast dosimetry protocols. *Phys. Med. Biol* 59 2127-2137 (LINK)

EUREF 2014 Protocol for the Quality Control of the Physical and Technical Aspects of Digital Breast Tomosynthesis Systems Draft version 0.15 January 2014 (LINK)

European guidelines for quality assurance in breast cancer screening and diagnosis. Fourth edition, Supplements. Perry N, Broeders M, de Wolf C, Törnberg S, Holland R, von Karsa L (eds.). European Commission, Office for Official Publications of the European Union, Luxembourg (LINK)

International Atomic Energy Agency (IAEA) 2006 *Dosimetry in diagnostic radiology: an international code of practice.* Technical Reports Series no. 457. (Vienna, Austria: IAEA). <http://www-pub.iaea.org/MTCD/publications/PDF/TRS457_web.pdf>

Institute of Physics and Engineering in Medicine (IPEM) 2005 *The commissioning and routine testing of mammographic X-ray systems.* IPEM Report 89 (York, United Kingdom: IPEM)

**MEAN GLANDULAR DOSE CONVERSION FACTORS**

*2D PROJECTION MAMMOGRAPHY*

In the IPEM, European and IAEA breast dosimetry protocols for 2D mammography the MEAN glandular dose (MGD) is estimated using

$D = Kgcs$ (1)

where $K$ is the incident air kerma (without backscatter) at the upper surface of the breast and $g$, $c$ and $s$ are conversion factors taken from the work of Dance (1990) and Dance et al. (2000, 2009, 2011). Multiplication by the $g$-factor gives the AGD for a breast of glandularity of 50% and the $c$-factor corrects for the difference in breast composition from 50% glandularity (Dance et al., 2000; Dance et al., 2011). The values of $g$ and $c$ provided in the original publications and in the protocols are tabulated against HVL and compressed breast thickness. In the case of the $c$-factor data are provided for a series of breast glandularities and also for typical breast glandularities for women attending the United Kingdom Breast Screening Programme. The $s$-factor corrects for differences in dose at the same HVL and breast thickness due to the choice of X-ray spectrum.

The paper by Dance et al. (2000) also provides thicknesses of PMMA phantoms which are equivalent to typical breasts. In this case it is important to note that the PMMA thickness has been chosen to match the incident air kerma values at the upper surfaces of the phantom and simulated breast.

Values of the factors $g$, $c$ and $s$ for use for both patient dosimetry and dosimetry using PMMA phantoms are given below, and are reproduced (where appropriate) with permission from IOP publishing.

*DIGITAL BREAST TOMOSYNTHESIS*

In Dance et al (2011) the formalism of equation (1) has been extended to digital breast tomosynthesis (DBT) using

$D = KgcsT$ (2)

where for DBT using a series of full field projections the tomo factor $T$ for the complete exposure is calculated using:

 $T= \sum\_{i}^{}α\_{i}t\_{i}$ (3)

Here the $t\_{i}$ are the tomo factors for the individual tomo projections and the $α\_{i}$ are the weights of the individual projections.

In the case of a DBT system using slit scanning a single tomo factor $T\_{s}$ is used. Values of $t$ are provided below as a function of projection angle and values of $T$ as a function of angular range. Values of $T$ or $T\_{s}$are also provided for selected commercially available (at the time of writing) DBT systems.

*CONTRAST ENHANCED DIGITAL MAMMOGRAPHY*

Contrast enhanced digital mammography uses X-ray spectra which are much harder than those employed for conventional projection mammography. In Dance et al (2014) values of the $g,$ $c$ and $s$ conversion factors are given for use with such spectra from W/Cu, Mo/Cu and Rh/Cu target filter combinations. These factors are also provided below.

***References***

Dance D R 1990 Monte Carlo calculation of conversion factors for the estimation of mean glandular breast dose. *Phys. Med. Biol*. **35** 1211-1219.

Dance D R, Skinner C L, Young K C, Beckett J R and Kotre C J 2000. Additional factors for the estimation of mean glandular breast dose using the UK mammography dosimetry protocol *Phys. Med. Biol.* 45 3225-3240.

Dance D R, Young K C and van Engen R E 2009 Further factors for the estimation of mean glandular dose using the United Kingdom, European and IAEA dosimetry protocols. *Phys. Med. Biol* **56** 4361-72

Dance D R, Young K C and van Engen R E 2011 Estimation of mean glandular dose for breast tomosynthesis: factors for use with the UK, European and IAEA dosimetry protocols. *Phys. Med. Biol 54* 453-471

Dance D R, Young K C 2014 Estimation of mean glandular dose for contrast enhanced digital mammography: factors for use with the UK, European and IAEA breast dosimetry protocols. *Phys. Med. Biol* 59 2127-2137

EUREF 2014 Protocol for the Quality Control of the Physical and Technical Aspects of Digital Breast Tomosynthesis Systems Draft version 0.15 January 2014

European guidelines for quality assurance in breast cancer screening and diagnosis. Fourth edition, Supplements. Perry N, Broeders M, de Wolf C, Törnberg S, Holland R, von Karsa L (eds.). European Commission, Office for Official Publications of the European Union, Luxembourg

International Atomic Energy Agency (IAEA) 2006 *Dosimetry in diagnostic radiology: an international code of practice.* Technical Reports Series no. 457. (Vienna, Austria: IAEA).

Institute of Physics and Engineering in Medicine (IPEM) 2005 *The commissioning and routine testing of mammographic X-ray systems.* IPEM Report 89 (York, United Kingdom: IPEM)

**DATA TABLES**

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**Note that when calculating the MGD for measurements using PMMA, the** $g$**- and** $c$**-factors should be looked up for the breast thickness that is simulated (as per the tables below), and the incident air kerma used should be that at the upper surface of the PMMA.**

Table 1 $g$-factors for breasts simulated with PMMA [based on Dance et al 2000, 2009, 2011]

|  |  |  |  |
| --- | --- | --- | --- |
| PMMA thickness(mm) | Equiv. breast thickness(mm) | Gland. of equiv. breast (%) | $g$-factors (mGy/mGy) |
| HVL (mm Al) |
| 0.30 | 0.35 | 0.40 | 0.45 | 0.50 | 0.55 | 0.60 | 0.65 | 0.70 | 0.75 | 0.80 |
| 20 | 21 | 97 | 0.378 | 0.421 | 0.460 | 0.496 | 0.529 | 0.559 | 0.585 | 0.609 | 0.631 | 0.650 | 0.669 |
| 30 | 32 | 67 | 0.261 | 0.294 | 0.326 | 0.357 | 0.388 | 0.419 | 0.448 | 0.473 | 0.495 | 0.516 | 0.536 |
| 40 | 45 | 41 | 0.183 | 0.208 | 0.232 | 0.258 | 0.285 | 0.311 | 0.339 | 0.366 | 0.387 | 0.406 | 0.425 |
| 45 | 53 | 29 | 0.155 | 0.177 | 0.198 | 0.220 | 0.245 | 0.272 | 0.295 | 0.317 | 0.336 | 0.354 | 0.372 |
| 50 | 60 | 20 | 0.135 | 0.154 | 0.172 | 0.192 | 0.214 | 0.236 | 0.261 | 0.282 | 0.300 | 0.317 | 0.333 |
| 60 | 75 | 9 | 0.106 | 0.121 | 0.136 | 0.152 | 0.166 | 0.189 | 0.210 | 0.228 | 0.243 | 0.257 | 0.272 |
| 70 | 90 | 4 | 0.086 | 0.098 | 0.111 | 0.123 | 0.136 | 0.154 | 0.172 | 0.188 | 0.202 | 0.214 | 0.227 |
| 80 | 103 | 3 | 0.074 | 0.085 | 0.096 | 0.106 | 0.117 | 0.133 | 0.149 | 0.163 | 0.176 | 0.187 | 0.199 |

Table 2 $c$-factors for breasts simulated with PMMA [based on Dance et al, 2000, 2009, 2011]

|  |  |  |  |
| --- | --- | --- | --- |
| PMMA thickness (mm) | Equiv. breast thickness (mm) | Gland.of equiv. breast (%) | $c$ -factors |
| HVL (mm Al) |
| 0.30 | 0.35 | 0.40 | 0.45 | 0.50 | 0.55 | 0.60 | 0.65 | 0.70 | 0.75 | 0.80 |
| 20 | 21 | 97 | 0.889 | 0.895 | 0.903 | 0.908 | 0.912 | 0.917 | 0.921 | 0.924 | 0.928 | 0.933 | 0.937 |
| 30 | 32 | 67 | 0.940 | 0.943 | 0.945 | 0.946 | 0.949 | 0.952 | 0.953 | 0.956 | 0.959 | 0.961 | 0.964 |
| 40 | 45 | 41 | 1.043 | 1.041 | 1.040 | 1.039 | 1.037 | 1.035 | 1.034 | 1.032 | 1.030 | 1.028 | 1.026 |
| 45 | 53 | 29 | 1.109 | 1.105 | 1.102 | 1.099 | 1.096 | 1.091 | 1.088 | 1.082 | 1.078 | 1.073 | 1.068 |
| 50 | 60 | 20 | 1.164 | 1.160 | 1.151 | 1.150 | 1.144 | 1.139 | 1.134 | 1.124 | 1.117 | 1.111 | 1.103 |
| 60 | 75 | 9 | 1.254 | 1.245 | 1.235 | 1.231 | 1.225 | 1.217 | 1.207 | 1.196 | 1.186 | 1.175 | 1.164 |
| 70 | 90 | 4 | 1.299 | 1.292 | 1.282 | 1.275 | 1.270 | 1.260 | 1.249 | 1.236 | 1.225 | 1.213 | 1.200 |
| 80 | 103 | 3 | 1.307 | 1.299 | 1.292 | 1.287 | 1.283 | 1.273 | 1.262 | 1.249 | 1.238 | 1.226 | 1.213 |

Table 3 Typical HVL measurements for different tube voltage and target filter combinations. (Data include the effect on measured HVL of attenuation by a compression paddle.)

|  |  |
| --- | --- |
|  | HVL (mm Al) for target filter combination |
| kV | Mo Mo | Mo Rh | Rh Rh | W Rh | W Ag | W Al (0.5mm) | W Al (0.7mm) |
| 25 | 0.32 ± .02 | 0.38 ± .02 | 0.37 ± .02 | 0.50 ± .03 | 0.51 ± .03 | 0.34 ± .03 | 0.42 ± .03 |
| 28 | 0.35 ± .02 | 0.42 ± .02 | 0.42 ± .02 | 0.53 ± .03 | 0.58 ± .03 | 0.39 ± .03 | 0.49 ± .03 |
| 31 | 0.38 ± .02 | 0.45 ± .02 | 0.45 ± .02 | 0.56 ± .03 | 0.61 ± .03 | 0.44 ± .03 | 0.55 ± .03 |
| 34 | 0.40 ± .02 | 0.47 ± .02 | 0.47 ± .02 | 0.59 ± .03 | 0.64 ± .03 | 0.49 ± .03 | 0.61 ± .03 |
| 37 |  |  |  | 0.62 ± .03  | 0.67 ± .03 | 0.53 ± .03 | 0.66 ± .03 |

Table 4a $s$-factors for clinically used spectra [Dance et al 2000, 2009].

|  |  |  |  |
| --- | --- | --- | --- |
| Target material | Filter material | Filter thickness (m) | $s$-factor |
| Mo | Mo | 30 | 1.000 |
| Mo | Rh | 25 | 1.017 |
| Rh | Rh | 25 | 1.061 |
| W | Rh | 50-60 | 1.042 |
| W | Ag | 50-75 | 1.042 |

Table 4b $s$-factors for a tungsten target filtered by 0.5 mm aluminium [Dance et al 2009].

|  |  |  |
| --- | --- | --- |
| PMMA thickness (mm) | Equiv breast thickness(mm) | $s$-factor |
| 20 | 21 | 1.075 |
| 30 | 32 | 1.104 |
| 40 | 45 | 1.134 |
| 45 | 53 | 1.149 |
| 50 | 60 | 1.160 |
| 60 | 75 | 1.181 |
| 70 | 90 | 1.198 |
| 80 | 103 | 1.208 |

Table 4c $s$-factors for a tungsten target filtered by 0.7 mm aluminium [based on Dance et al 2011].

|  |  |  |
| --- | --- | --- |
| PMMA thickness (mm) | Equiv breast thickness(mm) | $s$-factor |
| 20 | 21 | 1.052 |
| 30 | 32 | 1.064 |
| 40 | 45 | 1.082 |
| 45 | 53 | 1.094 |
| 50 | 60 | 1.105 |
| 60 | 75 | 1.123 |
| 70 | 90 | 1.136 |
| 80 | 103 | 1.142 |

Table 4d $s$-factors for a tungsten target filtered by 0.5 mm aluminium [Dance et al 2009].

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Breast thickness(mm) | Glandularityrange(%) | Typical glandularityage 50-64 | Typical glandularityage 40-49 | kV range(kV) | $s$-factor |
| 20 | 80-100 | 100 | 100 | 25-40 | 1.069 |
| 30 | 62-82 | 72 | 82 | 29-40 | 1.104 |
| 40 | 40-65 | 50 | 65 | 29-40 | 1.127 |
| 50 | 23-49 | 33 | 49 | 30-40 | 1.139 |
| 60 | 11-35 | 21 | 35 | 30-40 | 1.154 |
| 70 | 2-24 | 12 | 24 | 30-40 | 1.180 |
| 80 | 0.1-17 | 7 | 14 | 30-40 | 1.187 |
| 90 | 0.1-14 | 4 | 8 | 30-40 | 1.198 |
| 100 | 0.1-13 | 3 | 5 | 30-40 | 1.206 |
| 110 | 0.1-13 | 3 | 5 | 30-40 | 1.212 |

Table 4e $s$-factors for a tungsten target filtered by 0.7 mm aluminium [Dance et al 2011].

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Breast thickness(mm) | Glandularityrange(%) | Typical glandularityage 50-64 | Typical glandularityage 40-49 | kV range(kV) | s-factor |
| 20 | 80-100 | 100 | 100 | 25-50 | 1.052 |
| 30 | 62-82 | 72 | 82 | 25-50 | 1.060 |
| 40 | 40-65 | 50 | 65 | 25-50 | 1.076 |
| 50 | 23-49 | 33 | 49 | 25-50 | 1.087 |
| 60 | 11-35 | 21 | 35 | 25-50 | 1.105 |
| 70 | 2-24 | 12 | 24 | 28-50 | 1.121 |
| 80 | 0.1-17 | 7 | 14 | 28-50 | 1.129 |
| 90 | 0.1-14 | 4 | 8 | 28-50 | 1.136 |
| 100 | 0.1-13 | 3 | 5 | 28-50 | 1.140 |
| 110 | 0.1-13 | 3 | 5 | 28-50 | 1.144 |

Table 5 $g$-factors (mGy/mGy) for breast thicknesses of 20-110 mm and the HVL range 0.30-0.60 mm Al [Dance 1990, Dance et al 2000, 2011)].

|  |  |
| --- | --- |
| Breast thickness (mm) | $g$-factors (mGy/mGy) |
| HVL mm Al |
| 0.30 | 0.35 | 0.40 | 0.45 | 0.50 | 0.55 | 0.60 | 0.65 | 0.70 | 0.75 | 0.80 |
| 20 | 0.390 | 0.433 | 0.473 | 0.509 | 0.543 | 0.573 | 0.587 | 0.622 | 0.644 | 0.663 | 0.682 |
| 30 | 0.274 | 0.309 | 0.342 | 0.374 | 0.406 | 0.437 | 0.466 | 0.491 | 0.514 | 0.535 | 0.555 |
| 40 | 0.207 | 0.235 | 0.261 | 0.289 | 0.318 | 0.346 | 0.374 | 0.399 | 0.421 | 0.441 | 0.460 |
| 50 | 0.164 | 0.187 | 0.209 | 0.232 | 0.258 | 0.287 | 0.310 | 0.332 | 0.352 | 0.371 | 0.389 |
| 60 | 0.135 | 0.154 | 0.172 | 0.192 | 0.214 | 0.236 | 0.261 | 0.282 | 0.300 | 0.317 | 0.333 |
| 70 | 0.114 | 0.130 | 0.145 | 0.163 | 0.177 | 0.202 | 0.224 | 0.244 | 0.259 | 0.274 | 0.289 |
| 80 | 0.098 | 0.112 | 0.126 | 0.140 | 0.154 | 0.175 | 0.195 | 0.212 | 0.227 | 0.241 | 0.254 |
| 90 | 0.086 | 0.098 | 0.1106 | 0.1233 | 0.1357 | 0.1543 | 0.1723 | 0.1879 | 0.2017 | 0.2143 | 0.2270 |
| 100 | 0.076 | 0.087 | 0.0986 | 0.1096 | 0.1207 | 0.1375 | 0.1540 | 0.1682 | 0.1809 | 0.1926 | 0.2044 |
| 110 | 0.069 | 0.079 | 0.0887 | 0.0988 | 0.1088 | 0.1240 | 0.1385 | 0.1520 | 0.1638 | 0.1746 | 0.1856 |

Table 6 $c$ -factors for average breasts for women in age group 50 to 64 [Dance et al 2000 and based on Dance et al 2011].

|  |  |  |
| --- | --- | --- |
| Breast thickness (mm) | Gland. | $c$-factors (mGy/mGy) |
| HVL (mm Al) |
| % | 0.30 | 0.35 | 0.40 | 0.45 | 0.50 | 0.55 | 0.60 | 0.65 | 0.70 | 0.75 | 0.80 |
| 20 | 100 | 0.885 | 0.891 | 0.900 | 0.905 | 0.910 | 0.914 | 0.919 | 0.923 | 0.928 | 0.932 | 0.936 |
| 30 | 72 | 0.925 | 0.929 | 0.931 | 0.933 | 0.937 | 0.940 | 0.941 | 0.947 | 0.950 | 0.953 | 0.956 |
| 40 | 50 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
| 50 | 33 | 1.086 | 1.082 | 1.081 | 1.078 | 1.075 | 1.071 | 1.069 | 1.064 | 1.060 | 1.057 | 1.053 |
| 60 | 21 | 1.164 | 1.160 | 1.151 | 1.150 | 1.144 | 1.139 | 1.134 | 1.124 | 1.117 | 1.111 | 1.103 |
| 70 | 12 | 1.232 | 1.225 | 1.214 | 1.208 | 1.204 | 1.196 | 1.188 | 1.176 | 1.167 | 1.157 | 1.147 |
| 80 | 7 | 1.275 | 1.265 | 1.257 | 1.254 | 1.247 | 1.237 | 1.227 | 1.213 | 1.202 | 1.191 | 1.179 |
| 90 | 4 | 1.299 | 1.292 | 1.282 | 1.275 | 1.270 | 1.260 | 1.249 | 1.236 | 1.225 | 1.213 | 1.200 |
| 100 | 3 | 1.307 | 1.298 | 1.290 | 1.286 | 1.283 | 1.272 | 1.261 | 1.248 | 1.236 | 1.224 | 1.211 |
| 110 | 3 | 1.306 | 1.301 | 1.294 | 1.291 | 1.283 | 1.274 | 1.266 | 1.251 | 1.240 | 1.228 | 1.215 |

Table 7 $c$ -factors for average breasts for women in age group 40 to 49 [Dance et al 2000 and based on Dance et al 2011]

|  |  |  |
| --- | --- | --- |
| Breast thickness (mm) | Gland. | $c$-factors (mGy/mGy) |
| HVL (mm Al) |
| % | 0.30 | 0.35 | 0.40 | 0.45 | 0.50 | 0.55 | 0.60 | 0.65 | 0.70 | 0.75 | 0.80 |
| 20 | 100 | 0.885 | 0.891 | 0.900 | 0.905 | 0.910 | 0.914 | 0.919 | 0.923 | 0.928 | 0.932 | 0.936 |
| 30 | 82 | 0.894 | 0.898 | 0.903 | 0.906 | 0.911 | 0.915 | 0.918 | 0.924 | 0.928 | 0.933 | 0.937 |
| 40 | 65 | 0.940 | 0.943 | 0.945 | 0.947 | 0.948 | 0.952 | 0.955 | 0.956 | 0.959 | 0.961 | 0.964 |
| 50 | 49 | 1.005 | 1.005 | 1.005 | 1.004 | 1.004 | 1.004 | 1.004 | 1.004 | 1.003 | 1.003 | 1.003 |
| 60 | 35 | 1.080 | 1.078 | 1.074 | 1.074 | 1.071 | 1.068 | 1.066 | 1.061 | 1.058 | 1.055 | 1.051 |
| 70 | 24 | 1.152 | 1.147 | 1.141 | 1.138 | 1.135 | 1.130 | 1.127 | 1.117 | 1.111 | 1.105 | 1.098 |
| 80 | 14 | 1.220 | 1.213 | 1.206 | 1.205 | 1.199 | 1.190 | 1.183 | 1.172 | 1.163 | 1.154 | 1.145 |
| 90 | 8 | 1.270 | 1.264 | 1.254 | 1.248 | 1.244 | 1.235 | 1.225 | 1.214 | 1.204 | 1.193 | 1.181 |
| 100 | 5 | 1.295 | 1.287 | 1.279 | 1.275 | 1.272 | 1.262 | 1.251 | 1.238 | 1.227 | 1.215 | 1.203 |
| 110 | 5 | 1.294 | 1.290 | 1.283 | 1.281 | 1.273 | 1.264 | 1.256 | 1.242 | 1.232 | 1.220 | 1.208 |

Table 8a $t$-factors (breast thickness) for the calculation of AGD for individual projections and the full field geometry [Dance et al 2011].

|  |  |
| --- | --- |
| Breast thickness | $t$-factorfor projection angle (degrees) |
| (mm) | 5 | 10 | 15 | 20 | 25 | 30 |
| 20 | 0.997 | 0.988 | 0.976 | 0.958 | 0.930 | 0.895 |
| 30 | 0.996 | 0.986 | 0.970 | 0.944 | 0.914 | 0.870 |
| 40 | 0.996 | 0.984 | 0.964 | 0.937 | 0.902 | 0.859 |
| 50 | 0.995 | 0.983 | 0.961 | 0.932 | 0.897 | 0.855 |
| 60 | 0.994 | 0.980 | 0.960 | 0.926 | 0.894 | 0.851 |
| 70 | 0.993 | 0.980 | 0.956 | 0.927 | 0.894 | 0.851 |
| 80 | 0.993 | 0.979 | 0.955 | 0.924 | 0.892 | 0.852 |
| 90 | 0.991 | 0.977 | 0.951 | 0.924 | 0.892 | 0.854 |
| 100 | 0.993 | 0.975 | 0.949 | 0.924 | 0.892 | 0.845 |
| 110 | 0.992 | 0.973 | 0.947 | 0.921 | 0.888 | 0.834 |

Table 8b $t$-factors (PMMA thickness) for the calculation of AGD for individual projections and the full field geometry [based on Dance et al 2011].

|  |  |  |
| --- | --- | --- |
| PMMAthickness | Equivalent breastthickness | $t$-factorfor projection angle (degrees) |
| (mm) | (mm) | 5 | 10 | 15 | 20 | 25 | 30 |
| 20 | 21 | 0.997 | 0.988 | 0.975 | 0.956 | 0.928 | 0.893 |
| 30 | 32 | 0.996 | 0.985 | 0.968 | 0.942 | 0.911 | 0.868 |
| 40 | 45 | 0.996 | 0.984 | 0.963 | 0.934 | 0.900 | 0.857 |
| 45 | 53 | 0.995 | 0.982 | 0.961 | 0.930 | 0.896 | 0.854 |
| 50 | 60 | 0.994 | 0.980 | 0.960 | 0.926 | 0.894 | 0.851 |
| 60 | 75 | 0.993 | 0.980 | 0.955 | 0.925 | 0.893 | 0.851 |
| 70 | 90 | 0.991 | 0.977 | 0.951 | 0.924 | 0.892 | 0.854 |
| 80 | 103 | 0.993 | 0.974 | 0.948 | 0.923 | 0.891 | 0.842 |

Table 9a $T$-factors (breast thickness) for different scan ranges and the full field geometry [Dance et al 2011].

|  |  |
| --- | --- |
| Breast thickness  | $T$-factorfor projection angular range of (degrees) |
| (mm) | -10 to +10 | -15 to +15 | -20 to +20 | -25 to +25 | -30 to +30 |
| 20 | 0.994 | 0.989 | 0.982 | 0.972 | 0.960 |
| 30 | 0.992 | 0.985 | 0.976 | 0.965 | 0.950 |
| 40 | 0.992 | 0.984 | 0.973 | 0.961 | 0.944 |
| 50 | 0.991 | 0.982 | 0.971 | 0.957 | 0.941 |
| 60 | 0.989 | 0.981 | 0.969 | 0.955 | 0.939 |
| 70 | 0.989 | 0.980 | 0.969 | 0.955 | 0.940 |
| 80 | 0.988 | 0.979 | 0.967 | 0.953 | 0.937 |
| 90 | 0.987 | 0.977 | 0.965 | 0.952 | 0.937 |
| 100 | 0.987 | 0.977 | 0.965 | 0.952 | 0.935 |
| 110 | 0.986 | 0.975 | 0.963 | 0.949 | 0.931 |

Table 9b $T$ -factors (PMMA thickness) for different scan ranges and the full field geometry [based on Dance et al 2011].

|  |  |  |
| --- | --- | --- |
| PMMA thickness | Equivalent breastthickness | $T$-factorfor projection angular range of (degrees) |
| (mm) | (mm) | -10 to +10 | -15 to +15 | -20 to +20 | -25 to +25 | -30 to +30 |
| 20 | 21 | 0.993 | 0.988 | 0.981 | 0.971 | 0.959 |
| 30 | 32 | 0.992 | 0.985 | 0.976 | 0.964 | 0.949 |
| 40 | 45 | 0.992 | 0.983 | 0.972 | 0.959 | 0.943 |
| 45 | 53 | 0.991 | 0.982 | 0.970 | 0.956 | 0.940 |
| 50 | 60 | 0.989 | 0.981 | 0.969 | 0.955 | 0.939 |
| 60 | 75 | 0.989 | 0.980 | 0.968 | 0.954 | 0.938 |
| 70 | 90 | 0.987 | 0.977 | 0.965 | 0.952 | 0.937 |
| 80 | 103 | 0.987 | 0.976 | 0.964 | 0.951 | 0.934 |

Table 10a $T$ -factors (breast thickness) for the following full field tomosynthesis systems: Hologic Selenia Dimensions (2011 model), Siemens Mammomat Inspiration tomographic system (2011 model), GE Essential (2013 model), IMS Giotto TOMO (2013 model) and Planmed Nuance Excel DBT (2013 model) [based on Dance et al 2011].

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Breast thickness (mm) | $T$ Fujifilm± 7.5° | $T$ Fujifilm± 20° | $T$ GE± 12.5° | $T$ Hologic± 7.5° | $T$ IMS ± 19° | $T$ Planmed± 15° | $T$ Siemens± 24° |
| 20 | 0.997 | 0.985 | 0.993 | 0.997 | 0.985 | 0.991 | 0.980 |
| 30 | 0.996 | 0.981 | 0.991 | 0.996 | 0.981 | 0.989 | 0.974 |
| 40 | 0.997 | 0.979 | 0.990 | 0.996 | 0.978 | 0.988 | 0.971 |
| 50 | 0.996 | 0.977 | 0.989 | 0.995 | 0.976 | 0.986 | 0.968 |
| 60 | 0.995 | 0.975 | 0.988 | 0.994 | 0.974 | 0.985 | 0.966 |
| 70 | 0.995 | 0.974 | 0.987 | 0.994 | 0.973 | 0.984 | 0.965 |
| 80 | 0.994 | 0.972 | 0.986 | 0.993 | 0.972 | 0.983 | 0.964 |
| 90 | 0.993 | 0.971 | 0.985 | 0.992 | 0.970 | 0.981 | 0.962 |
| 100 | 0.994 | 0.970 | 0.984 | 0.993 | 0.970 | 0.981 | 0.961 |
| 110 | 0.993 | 0.969 | 0.984 | 0.992 | 0.968 | 0.980 | 0.960 |

Table 10b $T$S factors (breast thickness) for the Philips Microdose system with scanning geometry (geometry and exposure values from 2010 prototype) [Dance et al 2011].

|  |  |
| --- | --- |
| Breast thickness (mm) | $T$Philips |
| 20 | 0.983 |
| 30 | 0.958 |
| 40 | 0.935 |
| 50 | 0.907 |
| 60 | 0.883 |
| 70 | 0.859 |
| 80 | 0.833 |
| 90 | 0.806 |
| 100 | 0.783 |
| 110 | 0.759 |

Table 11a $T$-factors (PMMA thickness) for the following full field tomosynthesis systems: Hologic Selenia Dimensions (geometry and exposure values for 2011 model), Siemens Mammomat Inspiration tomographic system (geometry and exposure values for 2011 model), GE Essential (2013 model), IMS Giotto TOMO (2013 model) and Planmed Clarity (2013 model) [based on Dance et al 2011].

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| PMMA thickness(mm) | Breast thickness (mm) | $T$Fujifilm± 7.5° | $T$Fujifilm± 20° | $T$GE± 12.5° | $T$Hologic± 7.5° | $T$IMS ± 19° | $T$Planmed± 15° | $T$Siemens± 24° |
| 20 | 21 | 0.997 | 0.985 | 0.993 | 0.997 | 0.985 | 0.991 | 0.979 |
| 30 | 32 | 0.996 | 0.980 | 0.991 | 0.996 | 0.980 | 0.988 | 0.973 |
| 40 | 45 | 0.996 | 0.978 | 0.990 | 0.996 | 0.977 | 0.987 | 0.969 |
| 45 | 53 | 0.995 | 0.976 | 0.989 | 0.995 | 0.976 | 0.986 | 0.968 |
| 50 | 60 | 0.995 | 0.975 | 0.988 | 0.994 | 0.974 | 0.985 | 0.966 |
| 60 | 75 | 0.994 | 0.973 | 0.987 | 0.994 | 0.973 | 0.984 | 0.964 |
| 70 | 90 | 0.993 | 0.971 | 0.985 | 0.992 | 0.970 | 0.981 | 0.962 |
| 80 | 103 | 0.994 | 0.969 | 0.984 | 0.993 | 0.969 | 0.980 | 0.961 |

Table 11b $T$S factors (PMMA thickness) for the Philips Microdose system with scanning geometry (geometry and exposure values from 2010 prototype) [based on Dance et al 2011].

|  |  |  |
| --- | --- | --- |
| PMMA thickness (mm) | Breast thickness (mm) | $T$Philips |
| 20 | 21 | 0.980 |
| 30 | 32 | 0.953 |
| 40 | 45 | 0.921 |
| 45 | 53 | 0.900 |
| 50 | 60 | 0.883 |
| 60 | 75 | 0.846 |
| 70 | 90 | 0.806 |
| 80 | 103 | 0.776 |

Table 12 $g$-factors for breasts simulated with PMMA for HVLs in the range 2.4-3.6 mm Al (used for CEDM). Factors are only to be used for spectra filtered by copper [Dance and Young, 2014]

|  |  |  |  |
| --- | --- | --- | --- |
| PMMA thickness(mm) | Equiv. breast thickness(mm) | Gland. of equiv. breast (%) | $g$-factors (mGy/mGy) |
| HVL (mm Al) |
| 2.4 | 2.6 | 2.8 | 3 | 3.2 | 3.4 | 3.6 |
| 20 | 21 | 97 | 0.995 | 1.012 | 1.026 | 1.040 | 1.052 | 1.063 | 1.073 |
| 30 | 32 | 67 | 0.902 | 0.923 | 0.942 | 0.959 | 0.974 | 0.988 | 0.999 |
| 40 | 45 | 41 | 0.794 | 0.819 | 0.841 | 0.860 | 0.878 | 0.894 | 0.907 |
| 45 | 53 | 29 | 0.732 | 0.757 | 0.780 | 0.801 | 0.820 | 0.837 | 0.851 |
| 50 | 60 | 20 | 0.681 | 0.706 | 0.730 | 0.751 | 0.770 | 0.787 | 0.803 |
| 60 | 75 | 9 | 0.589 | 0.613 | 0.636 | 0.657 | 0.676 | 0.694 | 0.709 |
| 70 | 90 | 4 | 0.510 | 0.534 | 0.555 | 0.576 | 0.594 | 0.612 | 0.627 |
| 80 | 103 | 3 | 0.456 | 0.478 | 0.498 | 0.517 | 0.535 | 0.551 | 0.566 |

Table 13 $c$-factors for breasts simulated with PMMA for HVLs in the range 2.4-3.6 mm Al (used for CEDM). Factors are only to be used for spectra filtered by copper [based on Dance and Young, 2014]

|  |  |  |  |
| --- | --- | --- | --- |
| PMMA thickness (mm) | Equiv. breast thickness (mm) | Glandof equiv. breast (%) | $c$-factors |
| HVL (mm Al) |
| 2.4 | 2.6 | 2.8 | 3 | 3.2 | 3.4 | 3.6 |
| 20 | 21 | 97 | 0.973 | 0.975 | 0.977 | 0.979 | 0.981 | 0.982 | 0.983 |
| 30 | 32 | 67 | 0.982 | 0.984 | 0.985 | 0.986 | 0.987 | 0.988 | 0.989 |
| 40 | 45 | 41 | 1.014 | 1.012 | 1.011 | 1.011 | 1.010 | 1.009 | 1.009 |
| 45 | 53 | 29 | 1.037 | 1.034 | 1.031 | 1.029 | 1.027 | 1.025 | 1.024 |
| 50 | 60 | 20 | 1.059 | 1.055 | 1.051 | 1.047 | 1.044 | 1.041 | 1.038 |
| 60 | 75 | 9 | 1.096 | 1.089 | 1.083 | 1.077 | 1.072 | 1.068 | 1.064 |
| 70 | 90 | 4 | 1.121 | 1.113 | 1.105 | 1.098 | 1.092 | 1.087 | 1.083 |
| 80 | 103 | 3 | 1.133 | 1.124 | 1.116 | 1.109 | 1.102 | 1.097 | 1.092 |

Table 14 $g$-factors for breasts of thickness 20-110 mm and HVLs the range 2.4-3.6 mm Al (used for CEDM). Factors are only to be used for spectra filtered by copper [Dance and Young, 2014]

|  |  |
| --- | --- |
| Breast thickness(mm) | $g$-factors (mGy/mGy) |
| HVL (mm Al) |
| 2.4 | 2.6 | 2.8 | 3 | 3.2 | 3.4 | 3.6 |
| 20 | 1.004 | 1.020 | 1.034 | 1.047 | 1.059 | 1.070 | 1.079 |
| 30 | 0.919 | 0.939 | 0.958 | 0.974 | 0.989 | 1.002 | 1.013 |
| 40 | 0.835 | 0.858 | 0.880 | 0.899 | 0.915 | 0.930 | 0.942 |
| 50 | 0.754 | 0.779 | 0.802 | 0.822 | 0.841 | 0.858 | 0.872 |
| 60 | 0.681 | 0.706 | 0.730 | 0.751 | 0.770 | 0.787 | 0.803 |
| 70 | 0.617 | 0.642 | 0.665 | 0.686 | 0.706 | 0.723 | 0.739 |
| 80 | 0.560 | 0.584 | 0.607 | 0.628 | 0.647 | 0.664 | 0.680 |
| 90 | 0.510 | 0.534 | 0.555 | 0.576 | 0.594 | 0.612 | 0.627 |
| 100 | 0.467 | 0.489 | 0.510 | 0.530 | 0.547 | 0.564 | 0.579 |
| 110 | 0.429 | 0.450 | 0.470 | 0.489 | 0.506 | 0.521 | 0.535 |

Table 15 $c$-factors for average breasts for women in age group 50-64 [Dance et al 2000, 2014] and HVLs the range 2.4-3.6 mm Al (used for CEDM). Factors are only to be used for spectra filtered by copper [Dance and Young, 2014]

|  |  |  |
| --- | --- | --- |
| Breast thickness(mm) | Gland. | $c$-factors (mGy/mGy) |
| % | HVL (mm Al) |
|  | 2.4 | 2.6 | 2.8 | 3 | 3.2 | 3.4 | 3.6 |
| 20 | 100 | 0.973 | 0.975 | 0.977 | 0.979 | 0.981 | 0.982 | 0.984 |
| 30 | 72 | 0.979 | 0.980 | 0.982 | 0.983 | 0.985 | 0.986 | 0.987 |
| 40 | 50 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
| 50 | 33 | 1.028 | 1.026 | 1.024 | 1.022 | 1.021 | 1.019 | 1.018 |
| 60 | 21 | 1.057 | 1.053 | 1.049 | 1.046 | 1.043 | 1.040 | 1.037 |
| 70 | 12 | 1.084 | 1.078 | 1.072 | 1.067 | 1.063 | 1.059 | 1.056 |
| 80 | 7 | 1.105 | 1.098 | 1.092 | 1.085 | 1.080 | 1.075 | 1.070 |
| 90 | 4 | 1.121 | 1.112 | 1.105 | 1.098 | 1.092 | 1.087 | 1.083 |
| 100 | 3 | 1.131 | 1.122 | 1.114 | 1.107 | 1.101 | 1.095 | 1.090 |
| 110 | 3 | 1.138 | 1.129 | 1.120 | 1.113 | 1.106 | 1.101 | 1.096 |

Table 16 $c$-factors for average breasts for women in age group 40-49 [Dance et al 2000, 2014] and HVLs the range 2.4-3.6 mm Al (used for CEDM). Factors are only to be used for spectra filtered by copper [Dance and Young, 2014]

|  |  |  |
| --- | --- | --- |
| Breast thickness(mm) | Gland. | $c$-factors (mGy/mGy) |
| % | HVL (mm Al) |
|  | 2.4 | 2.6 | 2.8 | 3 | 3.2 | 3.4 | 3.6 |
| 20 | 100 | 0.973 | 0.975 | 0.977 | 0.979 | 0.981 | 0.982 | 0.984 |
| 30 | 82 | 0.969 | 0.972 | 0.974 | 0.976 | 0.978 | 0.980 | 0.981 |
| 40 | 65 | 0.981 | 0.982 | 0.983 | 0.984 | 0.986 | 0.987 | 0.988 |
| 50 | 49 | 1.002 | 1.001 | 1.001 | 1.001 | 1.001 | 1.001 | 1.001 |
| 60 | 35 | 1.029 | 1.027 | 1.025 | 1.023 | 1.021 | 1.020 | 1.018 |
| 70 | 24 | 1.058 | 1.053 | 1.050 | 1.046 | 1.043 | 1.041 | 1.039 |
| 80 | 14 | 1.086 | 1.080 | 1.075 | 1.070 | 1.065 | 1.061 | 1.058 |
| 90 | 8 | 1.110 | 1.102 | 1.096 | 1.090 | 1.084 | 1.080 | 1.076 |
| 100 | 5 | 1.126 | 1.118 | 1.110 | 1.103 | 1.097 | 1.091 | 1.087 |
| 110 | 5 | 1.133 | 1.124 | 1.116 | 1.109 | 1.103 | 1.097 | 1.092 |