UCDAVIS
HEALTH SYSTEM

# SSDE: Coming Soon to a Scanner Near You! Updates on Head Coefficients (AAPM Report 293) and IEC Codification

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AAPM 2021
JULY 25–29 | VIRTUAL
63RD ANNUAL MEETING & EXHIBITION

CREATIVE SCIENCE. ADVANCING MEDICINE.

# OUTLINE

**BACKGROUND**

– Size-specific dose estimate (SSDE)
– SSDE for pediatric and body CT examinations (AAPM Report 204)

**SSDE for head CT (AAPM Report 293)**

– Monte Carlo simulations and phantom imaging
– $CTDI_{vol}$-to-SSDE conversion factors

**International Electrotechnical Corporation (IEC) codification of SSDE**

- Definitions
- Requirements and Limitations

**Conclusions**

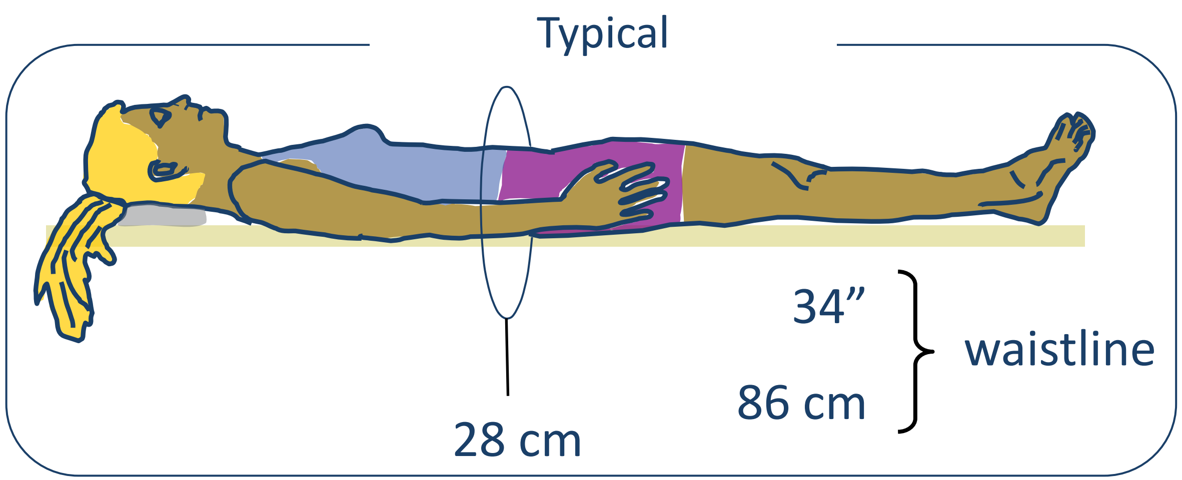
# DISCLOSURES

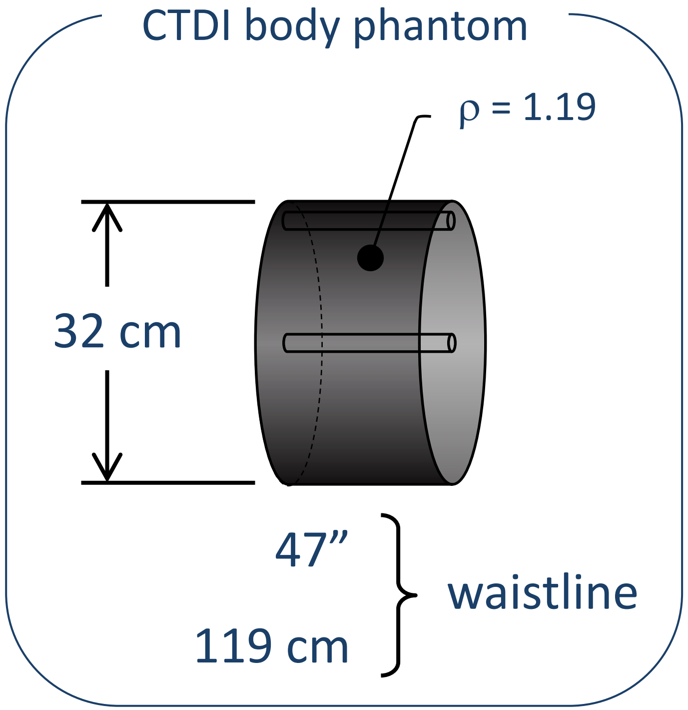
- Research funding from Canon Medical Systems
- Contractor for Izotropic Corporation of Canada

# CTDI$_{vol}$ limitations

- CTDI$_{vol}$ provides a standardized method for comparisons of CT **scanner output** for a standardized cylindrical phantom.

- CTDI$_{vol}$ does not account for patient habitus and is **not an estimate of actual patient dose.**



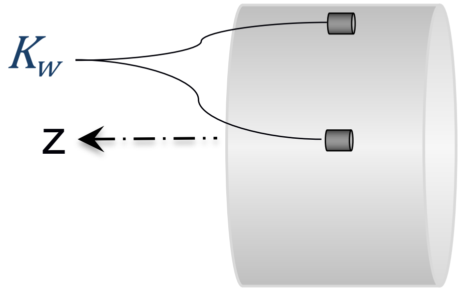



# Size-specific dose estimate (SSDE)

"*Absorbed dose* to the center section along the z-axis of a typical clinical CT scan"

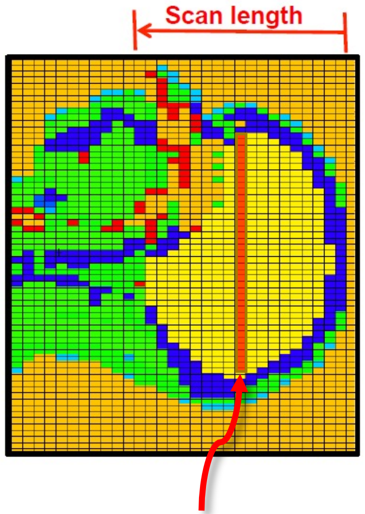
- AAPM Reports 204 and 293

## Physical measurements




$$D_{brain} = K_w \frac{\left(\frac{\mu_{en}}{\rho}\right)_{brain}}{\left(\frac{\mu_{en}}{\rho}\right)_{air}}$$

## Monte Carlo simulations

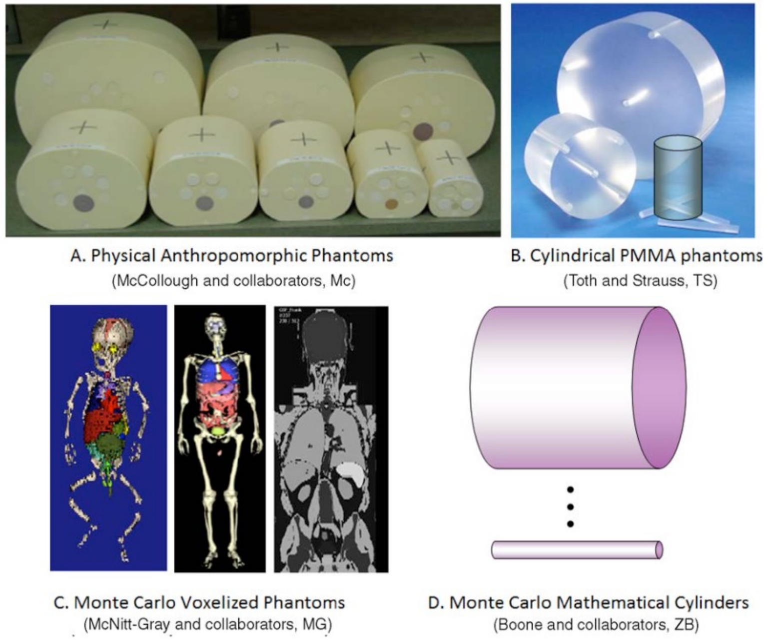


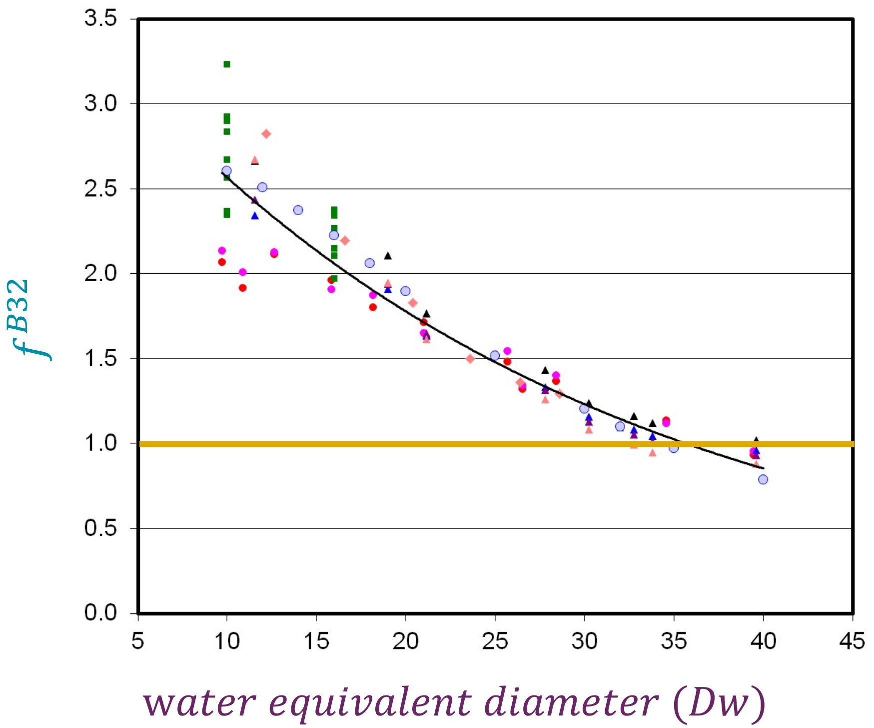

$$D_{brain} = \Psi \left(\frac{\mu_{en}}{\rho}\right)_{brain}$$

Voxelized head figure adopted from:
Hardy A.J., Bostani M., Hernandez A.M., Zankl M., McCollough C., Cagnon C., Boone J.M. McNitt-Gray M. Medical Physics 46(2); 2019

# TG 204: SSDE for pediatric and body CT examinations

**Purpose**: to provide a single set of conversion factors that can be used to convert $CTDI_{vol}$ to SSDE for pediatric and body CT examinations within 20% error.




$$f^{B32} = \frac{D}{CTDI_{vol,32}}$$

$$f^{B16} = \frac{D}{CTDI_{vol,16}}$$

***SSDE is especially important for the pediatric population because $CTDI_{vol}$ tends to underestimate the absorbed dose***

*Boone J.M. (Co-Chair), Strauss K.J. (Co-Chair), Cody D.D., McCollough C.H., McNitt-Gray M.F., Toth T.L.*

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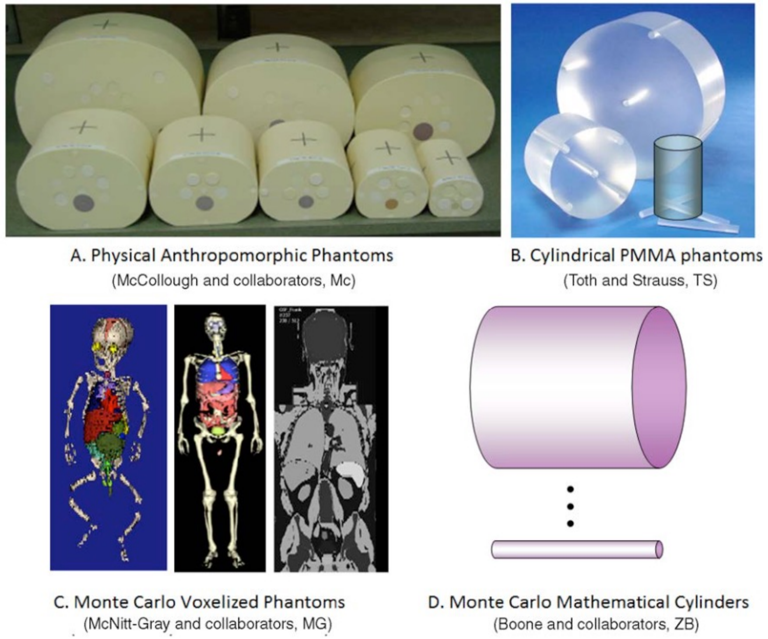


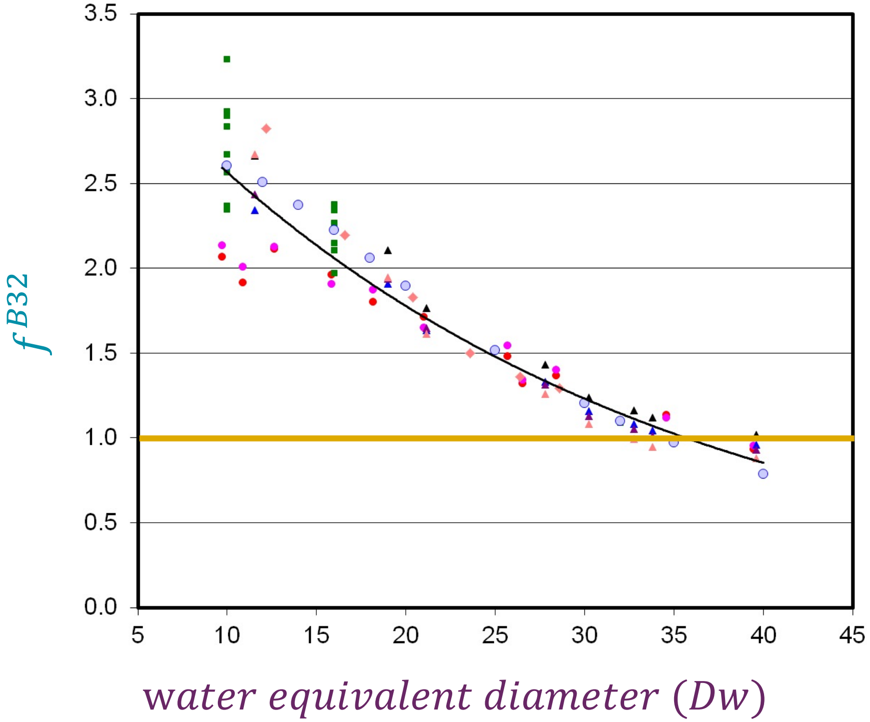


$$f^{B32} = \alpha e^{-\beta D_w}$$
$$\alpha = 3.7044$$
$$\beta = 0.0367$$

$$SSDE\ [mGy] = f^{B32} \times CTDI_{vol,32}$$

$$f^{B16} = \alpha e^{-\beta D_w}$$
$$\alpha = 1.8748$$
$$\beta = 0.0387$$

$$SSDE\ [mGy] = f^{B16} \times CTDI_{vol,16}$$

*Boone J.M. (Co-Chair), Strauss K.J. (Co-Chair), Cody D.D., McCollough C.H., McNitt-Gray M.F., Toth T.L.*

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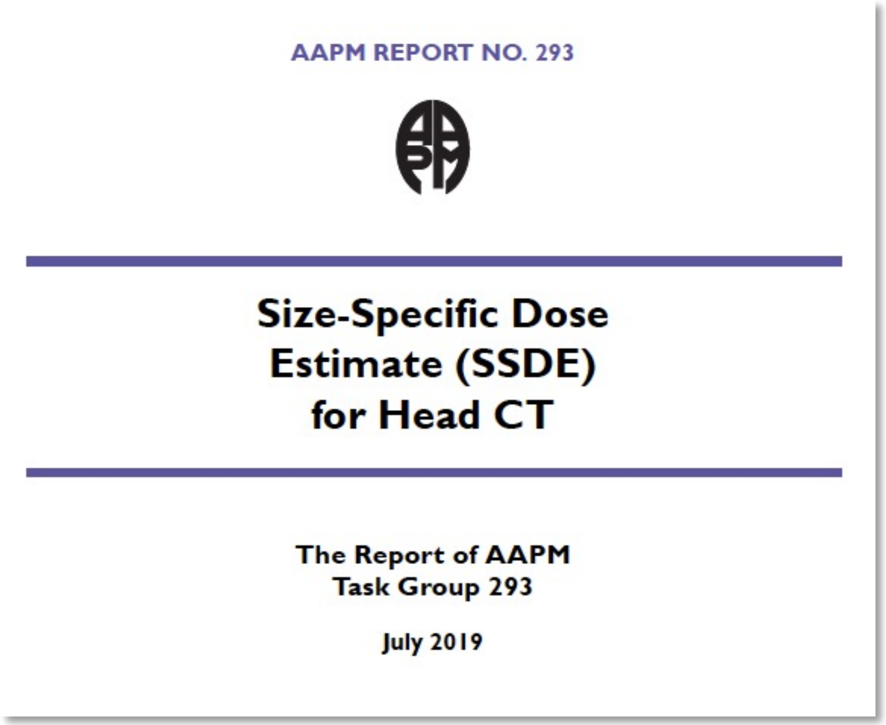
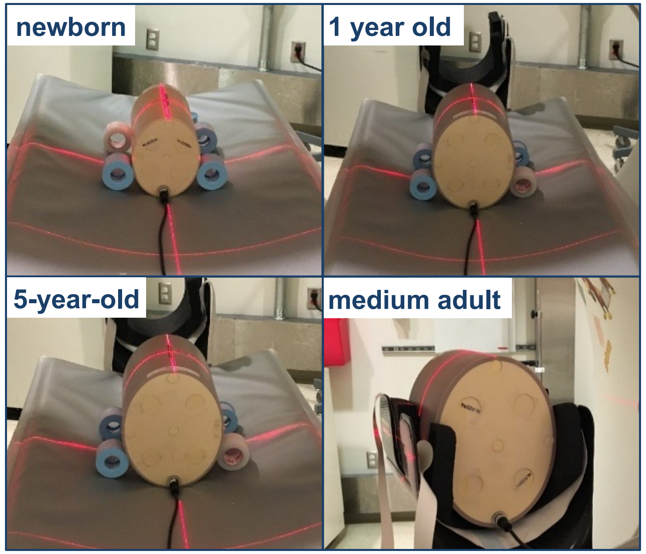
# SSDE for head CT examinations

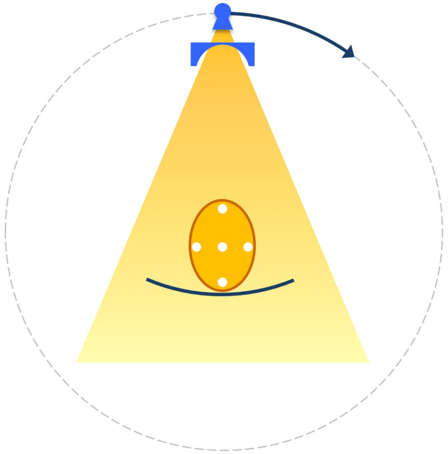

AAPM REPORT NO. 293

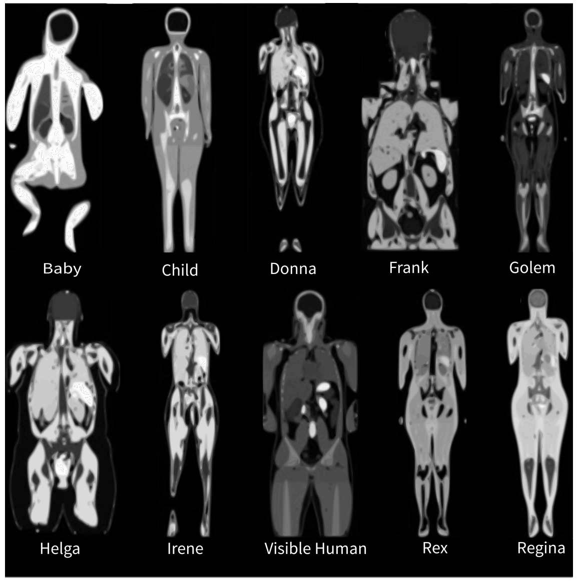
Size-Specific Dose Estimate (SSDE) for Head CT

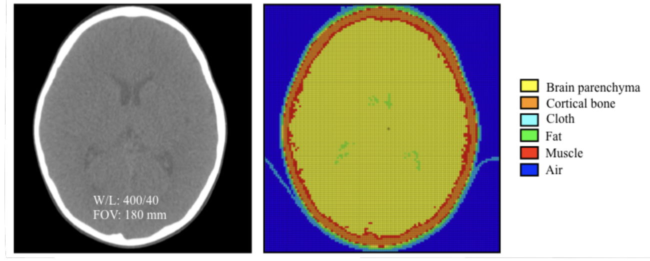
The Report of AAPM Task Group 293

July 2019



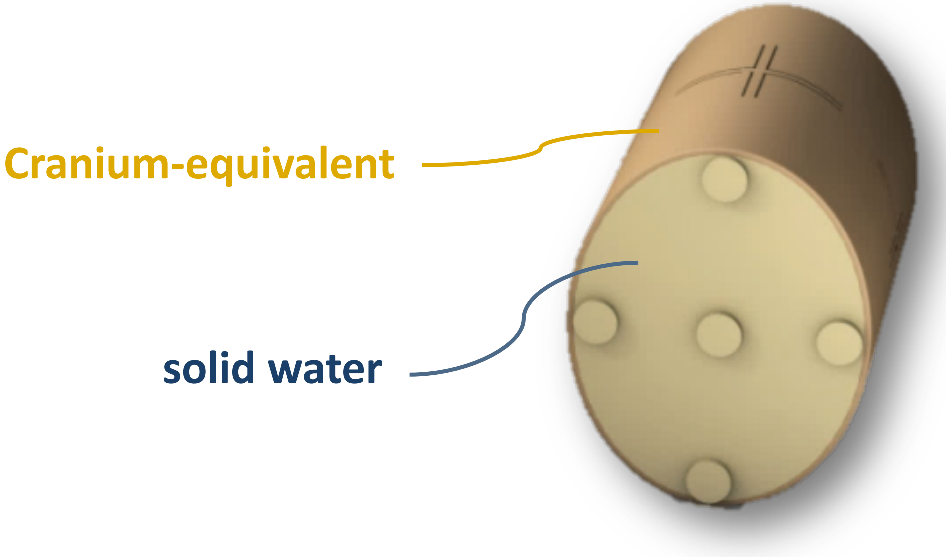



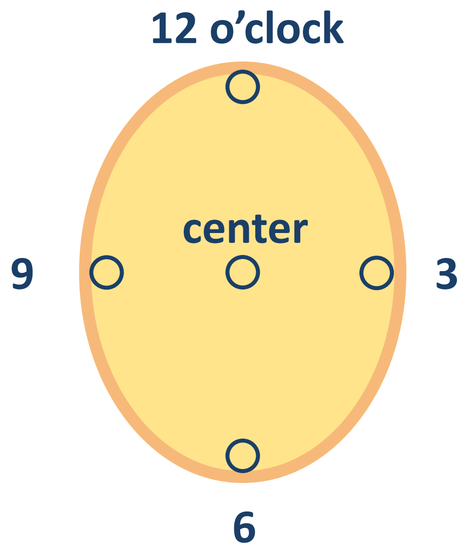



*Boone J.M. (Chair), Strauss K.J. (Vice-Chair), Hernandez A.M., Hardy A., Applegate K.E., Artz N.S., Brady S.L., Cody D.D., Kasraie N., McCollough C.H., McNitt-Gray M.*

# Age-specific, tissue-equivalent CIRS head phantoms



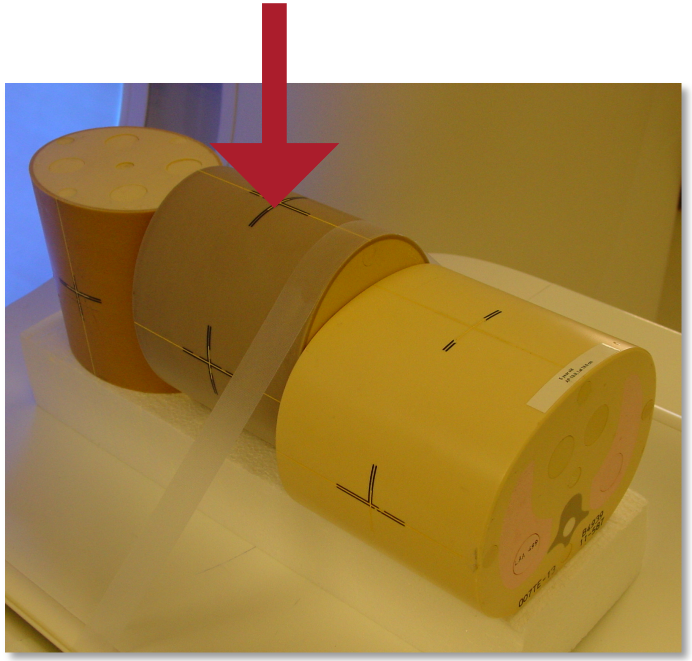




| | PA diameter (cm) | LR diameter (cm) | Cranium thickness (mm) | Cranium density (g/cc) |
|---|---|---|---|---|
| newborn | 12 | 9.5 | 2.5 | 1.41 |
| 1 year old | 16 | 12.0 | 3.0 | 1.45 |
| 5 year old | 17 | 13.5 | 3.5 | 1.52 |
| adult | 19 | 14.5 | 5.0 | 1.60 |

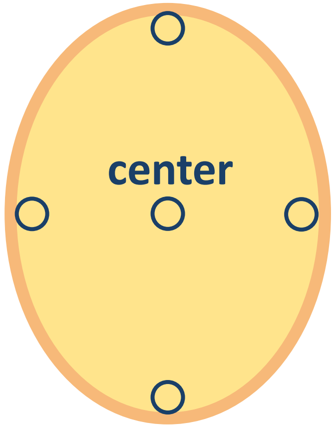
http://www.cirsinc.com/wp-content/uploads/2019/04/007TE-DS-120418.pdf

# Physical measurements in CIRS head phantoms

radcal.com



| | |
|---|---|
| Scanner | SIEMENS Force |
| kV: | 70 – 150 kV (10 kV intervals) |
| Mode: | Helical (pitch =1) |
| Nominal collimation (mm): | 115.2 mm |




$$K_w = \frac{1}{3} K_{center} + \frac{2}{3} avg\{K_{12o'clock}, K_3\}$$

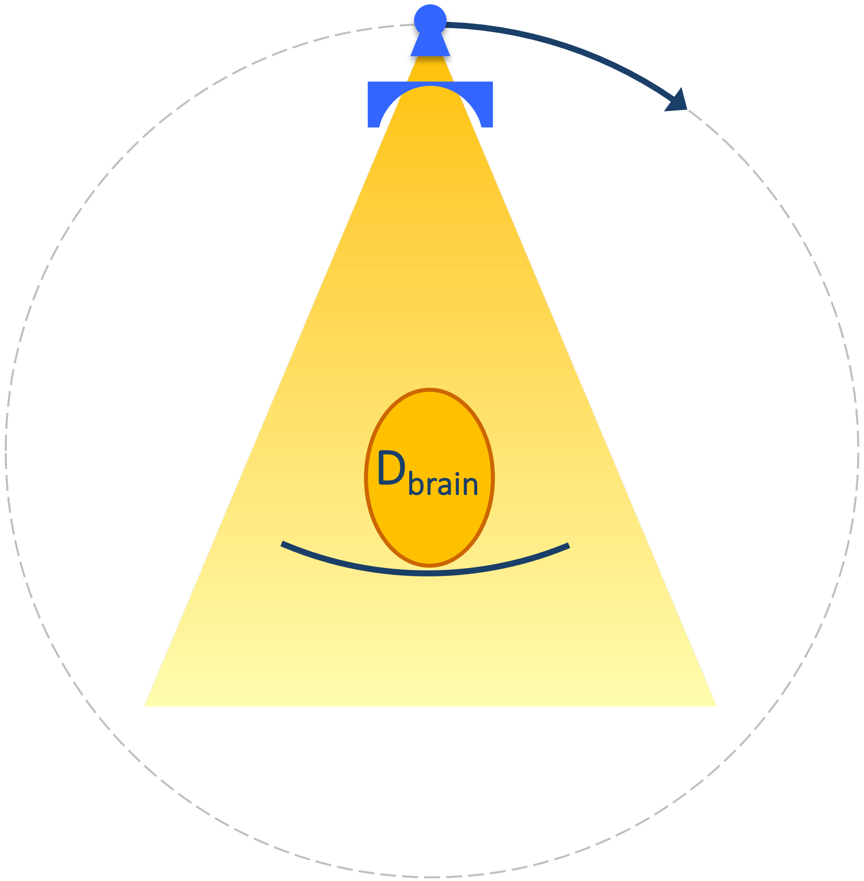
$$D_{brain} = 1.08 * K_w$$

$$f^{H16} = \frac{D_{brain}}{CTDI_{vol,16}}$$

*Measurements performed at Mayo Clinic (Cynthia McCollough)*

# MC simulations in virtual CIRS head phantoms

Dose to a 0.5 cm thick slab of solid water (brain tissue-mimicking) was estimated at the center (along z) of the scan volume

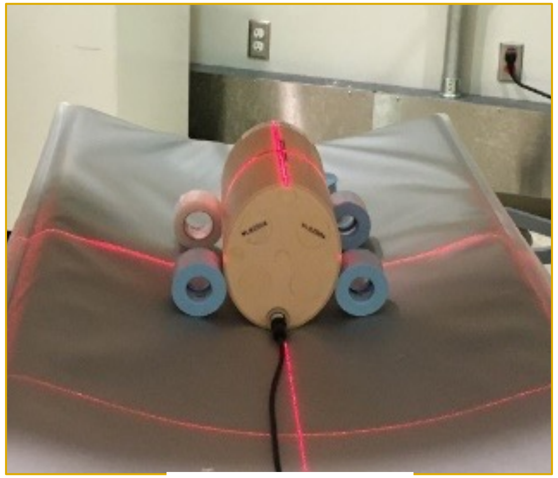



| Scanner: | GE VCT | GE Revolution |
|---|---|---|
| kV: | 80, 100, 120, 140 | |
| Mode: | Helical (pitch = 0.516) | Axial |
| Nominal collimation (mm): | 20 | 120-160 mm<br>Depending on phantom size |

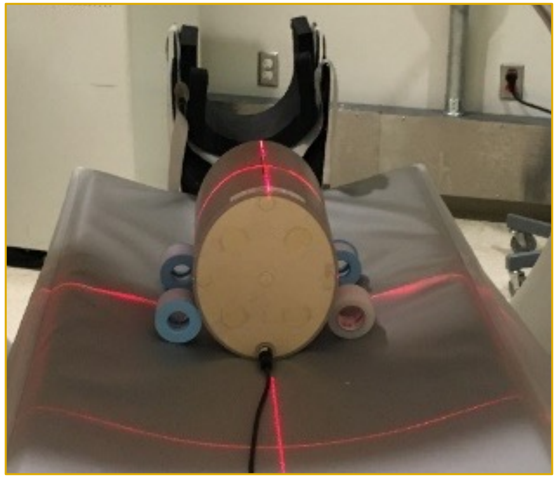
$$f^{H16} = \frac{D_{brain}}{CTDI_{vol,16}}$$

*Simulations performed at UC Davis (Andrew M. Hernandez and John M. Boone)*

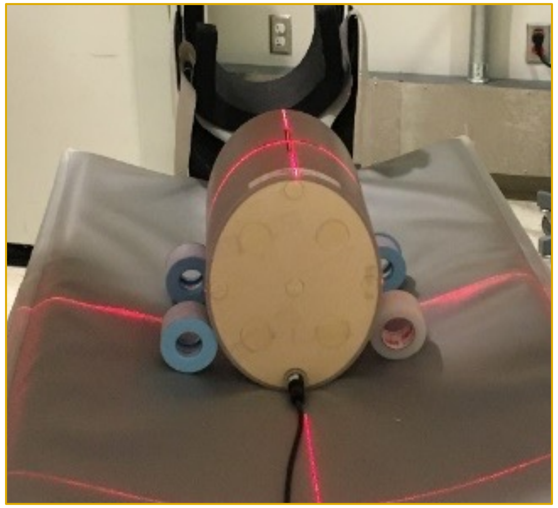
# MC validation against physical measurements



newborn



1 year old

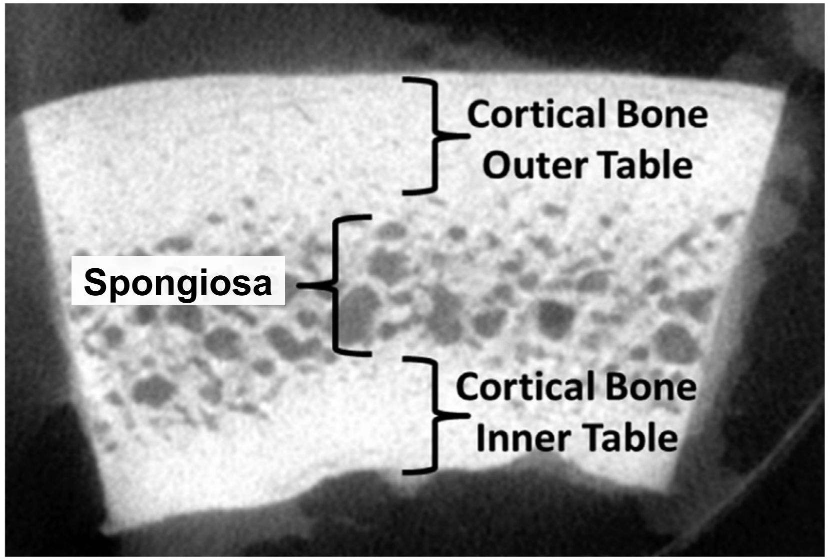


5-year-old

medium adult

*Physical measurements performed at St. Jude Children's Hospital (Keith J. Strauss, Samuel L. Brady, Nathan S. Artz)*

# MC simulations in mathematical head phantoms




Lillie, E. M. *et al.* (2016.) J. Bone Miner Res. 31(2):299–307.

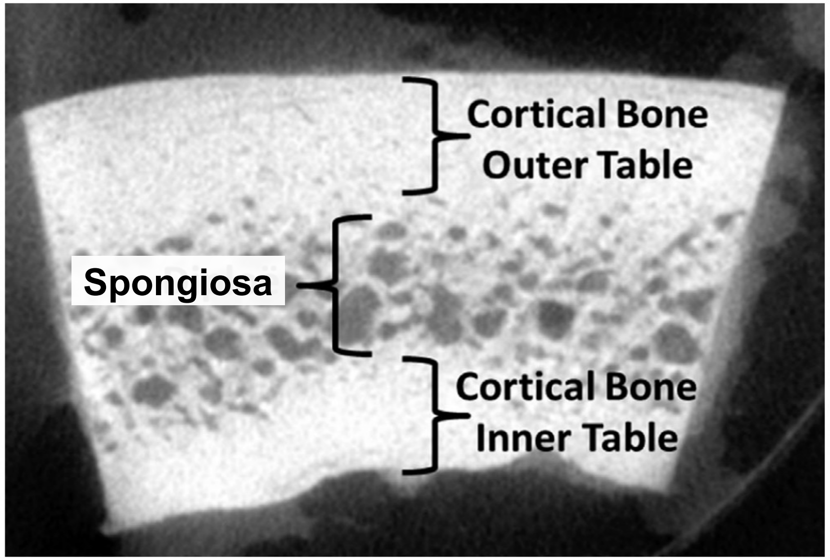
Red Marrow in the cranium expressed as % of active marrow in the body

| Age (yr) | Cranium (%) |
|---|---|
| 0 | 27.0 |
| 1 | 25.1 |
| 5 | 15.9 |
| 15 | 19.2 |
| 40 | 7.6 |
| *ICRP Report 70* | |

*Simulations performed at UC Davis (Andrew M. Hernandez and John M. Boone)*

# MC simulations in mathematical head phantoms

Mathematical **phantoms**, derived from ICRP 70, 46, 89 and other published data [Kleinman 2010], were **simulated** for estimation of **absorbed dose** to the **brain parenchyma**, **shallow marrow** (SM), and **red bone marrow** (RBM).




Lillie, E. M. *et al.* (2016.) J. Bone Miner Res. 31(2):299–307.

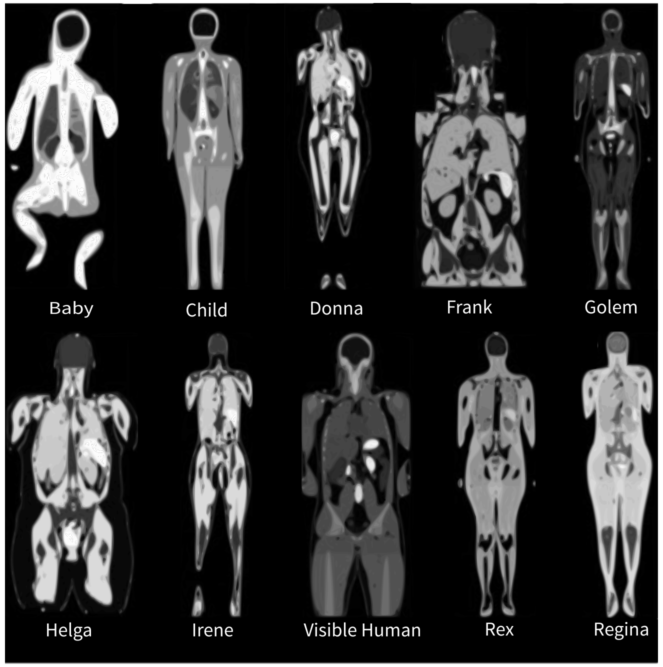
| Age (yrs) | PA | Lateral | $D_w$ (CV) | Cranium Thickness |
|---|---|---|---|---|
| 0 | 11.6 | 9.6 | 11.6 (1.1%) | 0.34 |
| 1 | 16.4 | 13.2 | 15.8 (0.9%) | 0.41 |
| 5 | 18.4 | 14.6 | 17.7 (1.0%) | 0.52 |
| 21 | 20.6 | 16.2 | 20.0 (1.2%) | 0.69 |

$$D_{head} = \frac{D_{brain}M_{brain} + D_{SM}M_{SM} + D_{RBM}M_{RBM}}{M_{brain} + M_{SM} + M_{RBM}} \approx D_{brain}$$

$$f^{H16} = \frac{D_{head}}{CTDI_{vol,16}}$$

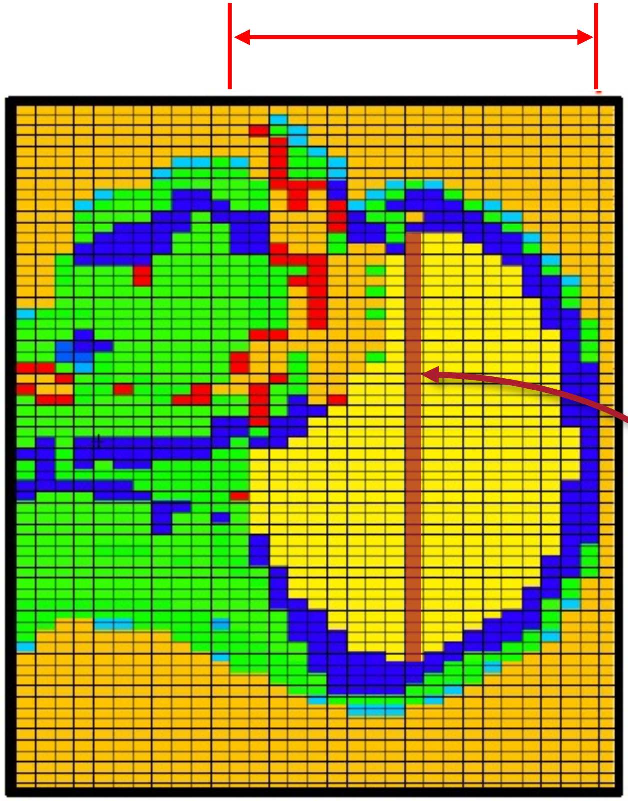
*Simulations performed at UC Davis (Andrew M. Hernandez and John M. Boone)*

# MC simulations in voxelized head models




- *8 from GSF family of patient models*
- *Two reference ICRP patient models*
- *5 voxelized patient models from routine pediatric head CT exams*

Absorbed dose to brain ($D_{brain}$) tallied in MCNP within a slab in the center of the scan volume




$$f^{H16} = \frac{D_{brain}}{CTDI_{vol,16}}$$

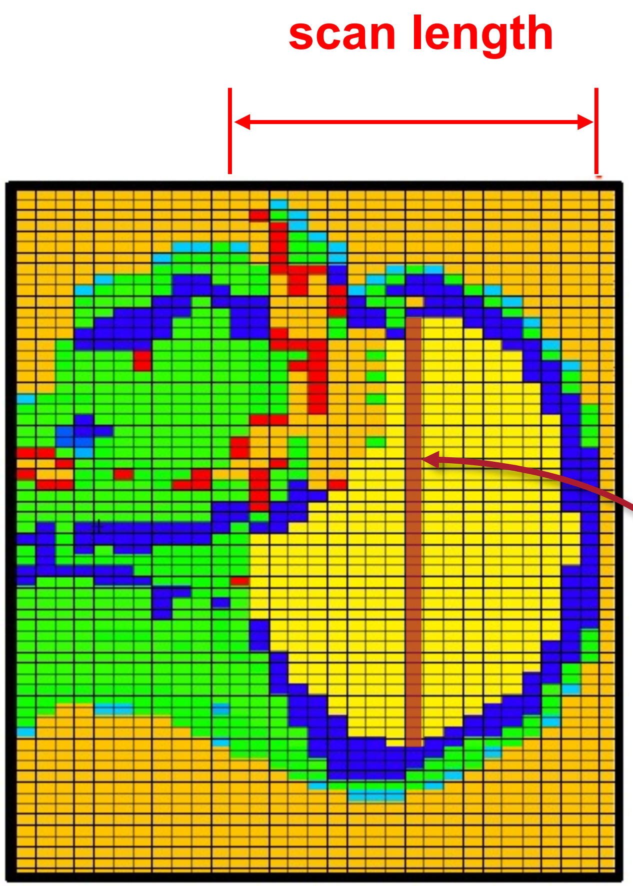
- Simulations performed at UCLA (Anthony Hardy and Michael McNitt-Gray)

Hardy A.J., Bostani M., Hernandez A.M., Zankl M., McCollough C., Cagnon C., Boone J.M. McNitt-Gray M. Medical Physics 46(2); 2019

# MC simulations in voxelized head models

Absorbed dose to brain ($D_{brain}$) tallied in MCNP within a slab in the center of the scan volume

| | |
|---|---|
| Scanner: | SIEMENS Sensation 64 |
| kV: | 120 kV |
| Mode: | Helical (pitch =0.55) |
| Nominal collimation (mm): | 28.8 |

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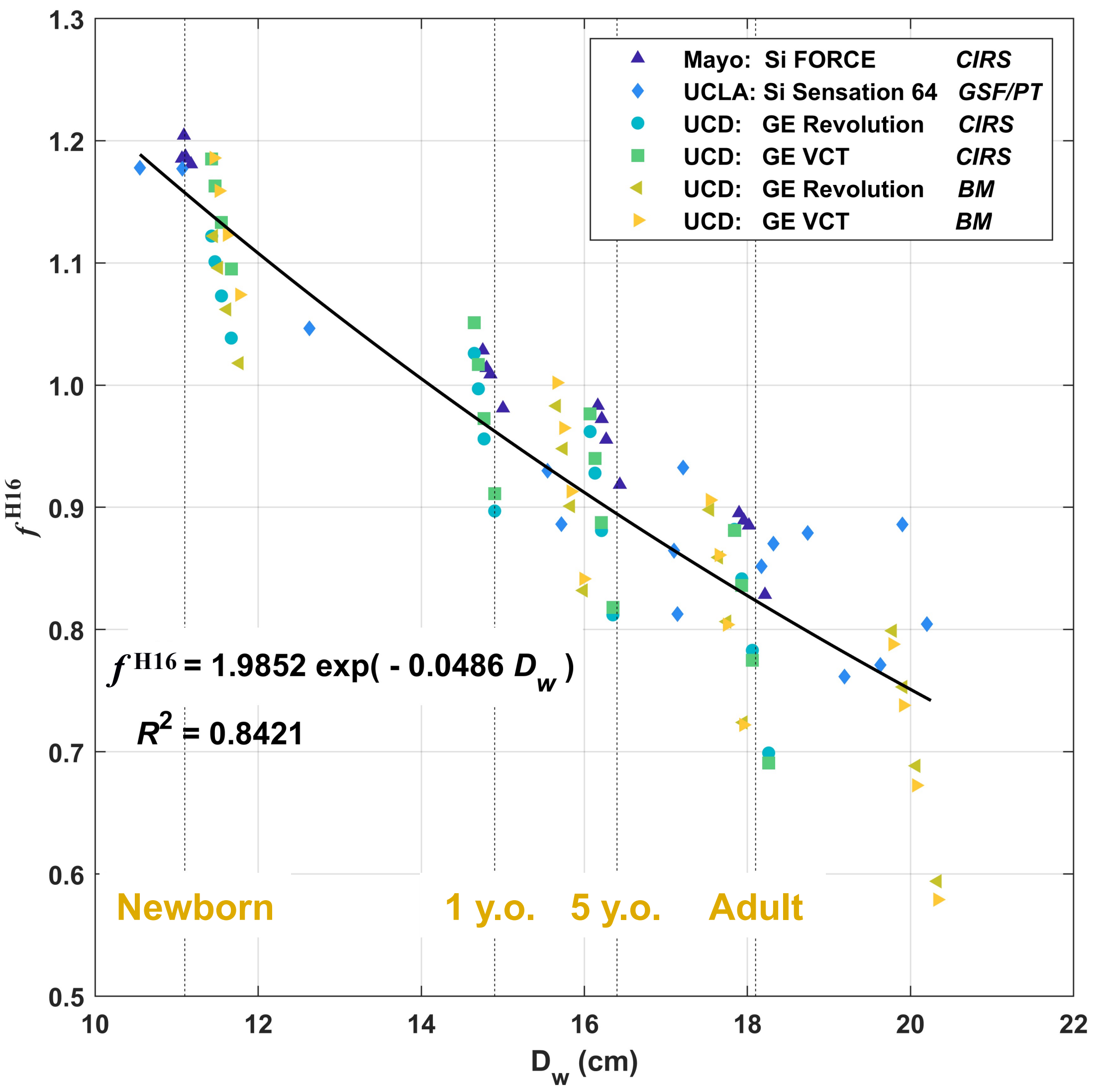
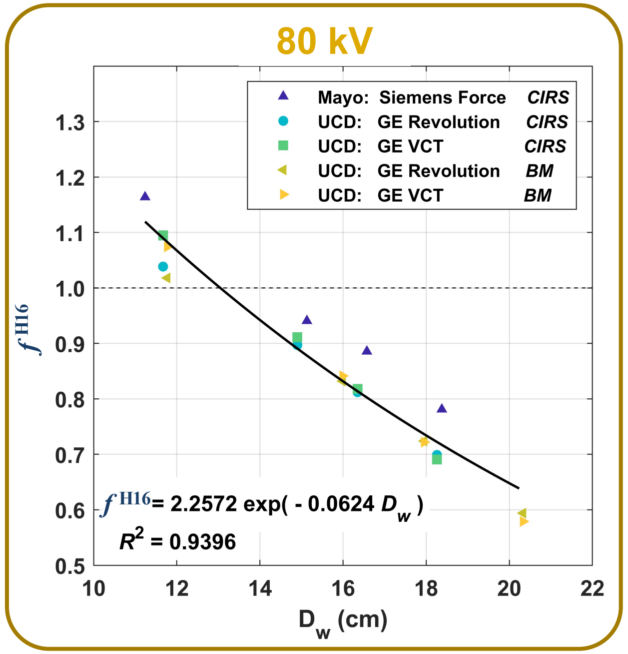
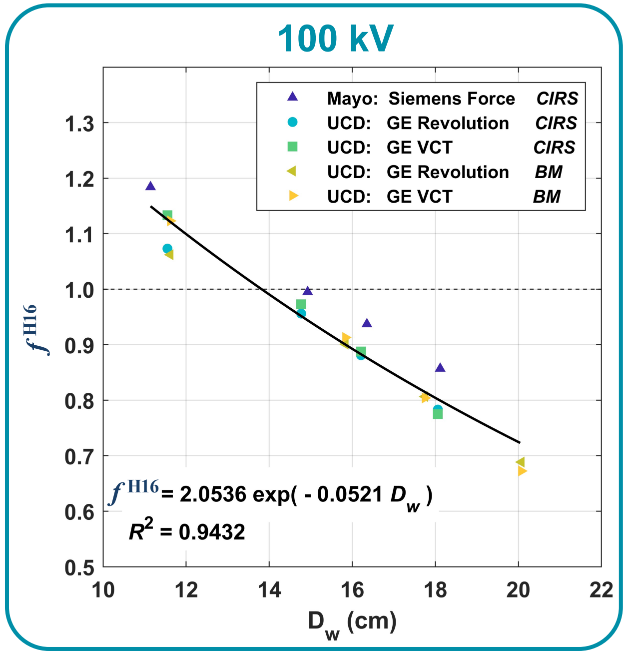
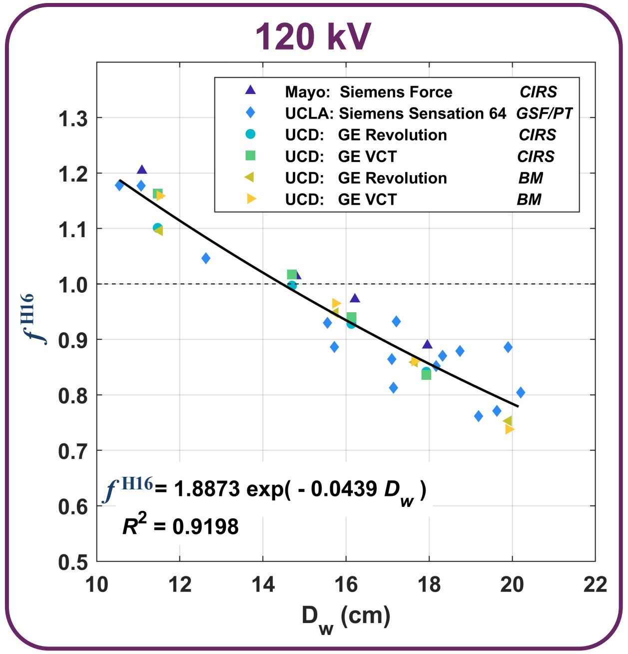
# Results: $CTDI_{vol}$-to-SSDE conversion factors

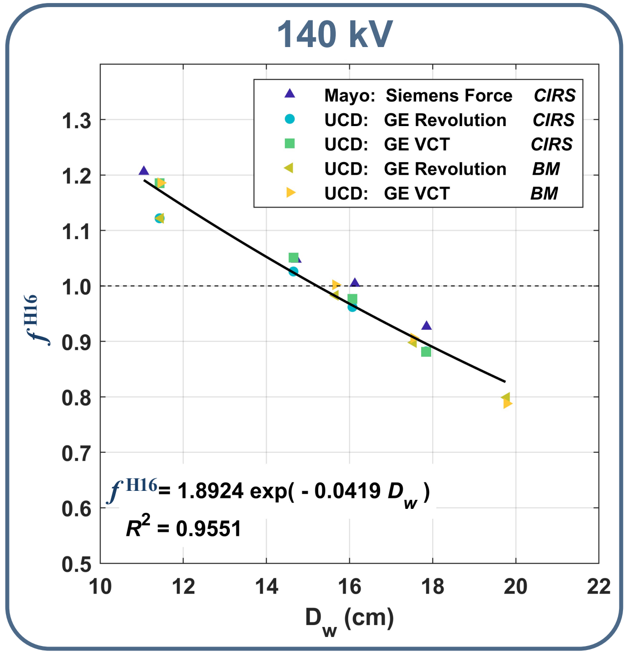


# Results: CTDI$_{vol}$-to-SSDE conversion factors



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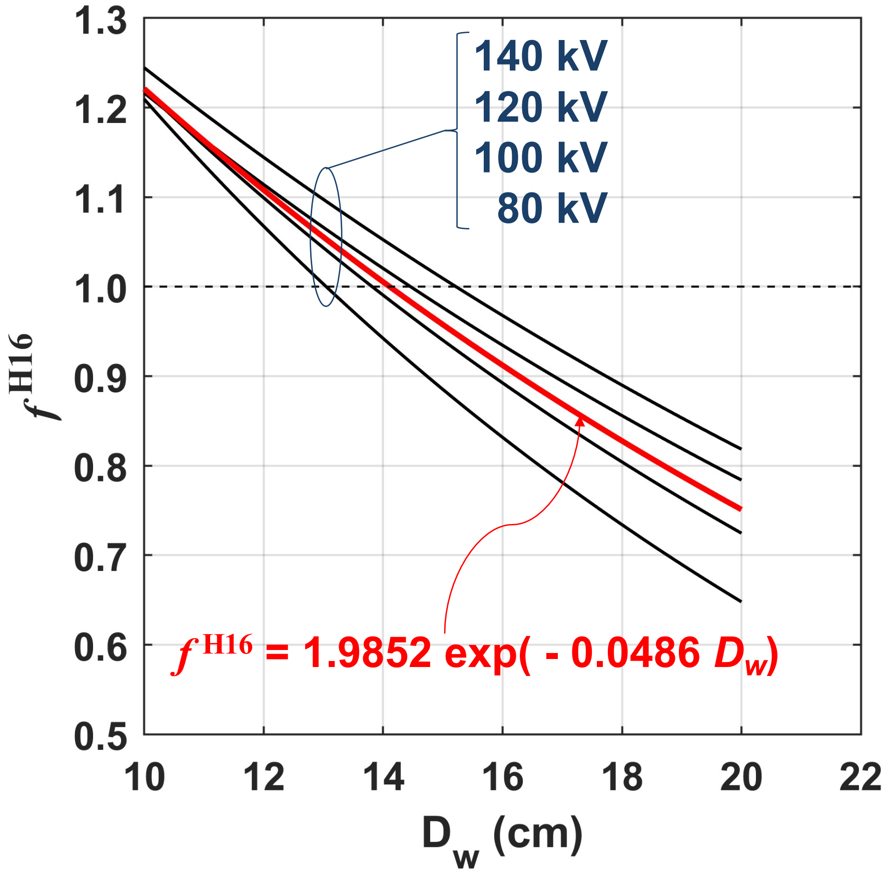

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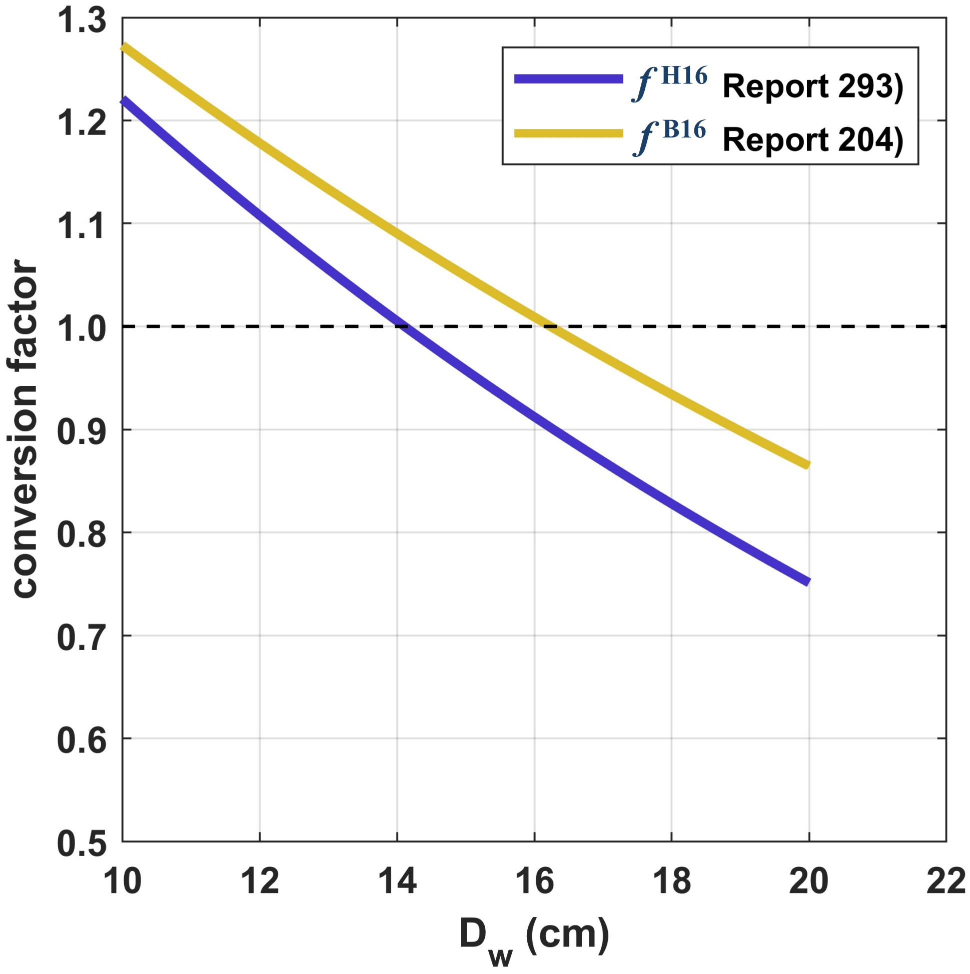


The conversion factors for **head CT** examinations (Report 293) are **consistently lower than for body** CT (Report 204) because of **attenuation of the skull**

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# **IEC 62985:** Methods for calculating SSDE for CT

IEC 62985

Edition 1.0 2019-09

**INTERNATIONAL STANDARD**

**NORME INTERNATIONALE**

**Methods for calculating size specific dose estimates (SSDE) for computed tomography**

**Méthodes de calcul de l'estimateur de dose morphologique (SSDE) en tomodensitométrie**

*Published on: 9/13/2019*

"[…] this document provides **standardized methods** and requirements for **calculating, displaying, or recording of SSDE, SSDE(z), WATER EQUIVALENT DIAMETER ($D_W$), and $D_W$(z),** where z represents a specific longitudinal position of the scanned object."

Note: the following slides describing IEC 62985 are in some cases abbreviated for the purpose of dissemination and understanding in this talk. Please refer to the IEC document for exact definitions and detailed explanations.

IEC 62985 [ https://webstore.iec.ch/publication/29540 ]

# IEC 62985: $CTDI_{vol}(z)$ and $D_w(z)$

**3.1**

**$CTDI_{VOL}$ AT LONGITUDINAL POSITION Z**

**$CTDI_{VOL}(z)$**

value quantifying the RADIATION output at position z for the selected CT CONDITIONS OF OPERATION.

**3.4**

**WATER EQUIVALENT DIAMETER AT LONGITUDINAL POSITION Z**

**$D_W(z)$**

diameter in cm, of a cylinder of water having the same averaged ABSORBED DOSE as the material contained in an axial plane at longitudinal position z of the object scanned, calculable for a material of any composition, and quantifying the ATTENUATION of any material in terms of the ATTENUATION of water

IEC 62985 [ https://webstore.iec.ch/publication/29540 ]

# **IEC 62985:** CTDI$_{vol}$-to-SSDE conversion factor

$$f\left(D_w(z)\right) = a \times e^{-bD_w(z)}$$

| Table A.1 | | |
|---|---|---|
| | **a** | **b** |
| **TG 204: Body exam and CTDI$_{vol}$ measured with 32 cm CTDI phantom** | 3.7044 | 0.0367 |
| **TG 204: Body exam and CTDI$_{vol}$ measured with 32 cm CTDI phantom** | 1.8748 | 0.0387 |
| **TG 293: Head exam and CTDI$_{vol}$ measured with 16 cm CTDI phantom** | 1.9852 | 0.0486 |

IEC 62985 [ https://webstore.iec.ch/publication/29540 ]

# IEC 62985: SSDE definition

**3.9**
**SIZE SPECIFIC DOSE ESTIMATE AT LONGITUDINAL POSITION Z**
**SSDE(z)**
estimate of the average ABSORBED DOSE to the material contained in an axial plane at longitudinal position z within the RECONSTRUCTION LENGTH, expressed in units of mGy:

$$SSDE(z) = f\left(D_W(z)\right) \cdot CTDI_{VOL}(z)$$

**3.10**
**SIZE SPECIFIC DOSE ESTIMATE**
**SSDE**
arithmetic average of SSDE(z), calculated over the RECONSTRUCTION LENGTH at the same z-positions as the corresponding $D_W(z)$ values used to calculate $D_W$:

$$SSDE = \frac{1}{n} \cdot \sum_{i=1}^{n} SSDE(z_i)$$

where

$n$ is the number of z positions ($z_i,\ i = 1,2,\dots,n$) within the RECONSTRUCTION LENGTH

# **IEC 62985:** Requirements

5.1: Calculation of SSDE and Dw for CT scanners

SSDE and Dw:

- determined over the **reconstruction length** containing **patient-anatomy.**
- **not required** to be calculated, displayed or recorded **when a scanned projection radiograph does not exist** for given protocol or reconstruction length.

# **IEC 62985:** Requirements

## 5.2: Pre-scan display of SSDE for CT scanners

Except as identified in 5.1:

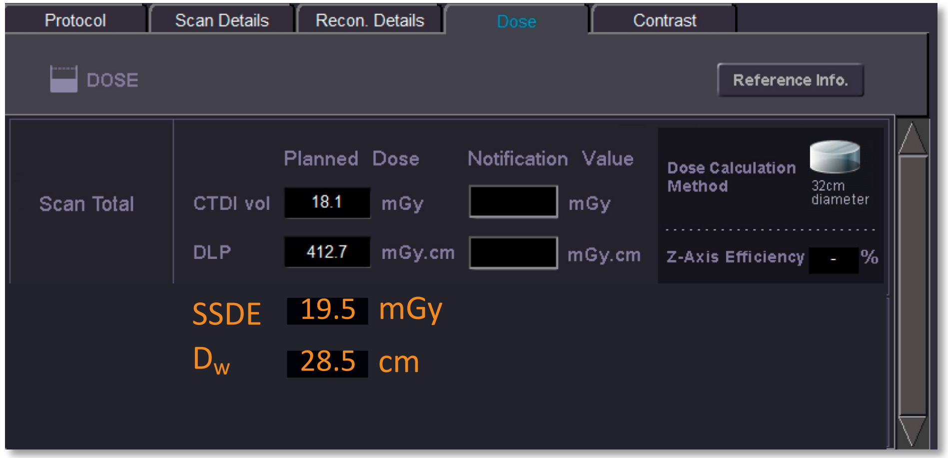
- **SSDE** (mGy units) shall be **displayed on the control panel prior to initiation of scanning sequence** on same screen and proximity to displayed CTDIvol

## 5.3: Post-scan updating of SSDE and Dw for CT scanners

Following a sequence of scanning:

- **Pre-scan SSDE and SSDE(z)** shall be **updated to account for changes** between pre-scan CTDIvol and post-scan CTDIvol
- **Pre-scan Dw and Dw(z)** shall be **updated as well**.

*Mock-up example of what to expect:*




CT console dose screenshot adopted from Canon Aquilion Precision User Manual.

# IEC 62985: Requirements

## 5.4: Pre and post-scan display of SSDE and Dw for CT scanners

For each protocol, the **pre- and post-scan SSDE**, and **pre- and post-scan Dw** shall be **displayed on the control panel** on same screen and in proximity to $CTDI_{vol}$

## 5.5: Post-scan recording of SSDE and Dw

IF DICOM radiation dose structured report (RDSR) …….

**has necessary fields:**

- Post-scan SSDE and Dw values (as well as SSDE(z) and Dw(z) at the interval used), shall be recorded in the DICOM RDSR.

**does not have necessary fields for recording SSDE and Dw**:

- Corresponding post-scan values shall be recorded as part of a dose report saved as an image.

**does not have necessary fields for recording SSDE(z) and Dw(z)** at interval used,

- Corresponding post-scan values do not need to be recorded..

# IEC 62985: Limitations

5.6: Limitations of calculation and display of SSDE and Dw

For **axial scanning with total table travel << N×T** OR patient **support is manually moved or remains stationary:**

- **CTDIvol overestimates average absorbed dose** that would accrue in phantom's central section. SSDE will propagate this error.

For **helical scanning when the product of a smaller number of rotation times the table travel per rotation << N x T:**

- **CTDIvol overestimates average absorbed dose** that would accrue in phantom's central section. SSDE will propagate this error.

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- Monte Carlo simulations and phantom imaging
- $CTDI_{vol}$-to-SSDE conversion factors

**International Electrotechnical Corporation (IEC) codification of SSDE**

- Definitions
- Requirements and Limitations

**Conclusions**

# Conclusions: So what?

## What is the utility of SSDE?

- Establish diagnostic reference levels across patient sizes
- CT patient dose monitoring and alerts that account for patient size
- More accurate reporting of patient dose for the ACR Dose Index Registry (for example), facilitating improved comparisons between regional and national values
- Improves risk predictions and therefore decision making in terms of potentially using other modalities such as MR and US

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# SSDE: Coming Soon to a Scanner Near You! Updates on Head Coefficients (Report 293) and IEC Codification

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## Thank you!

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