CT Dose: Towards Literacy

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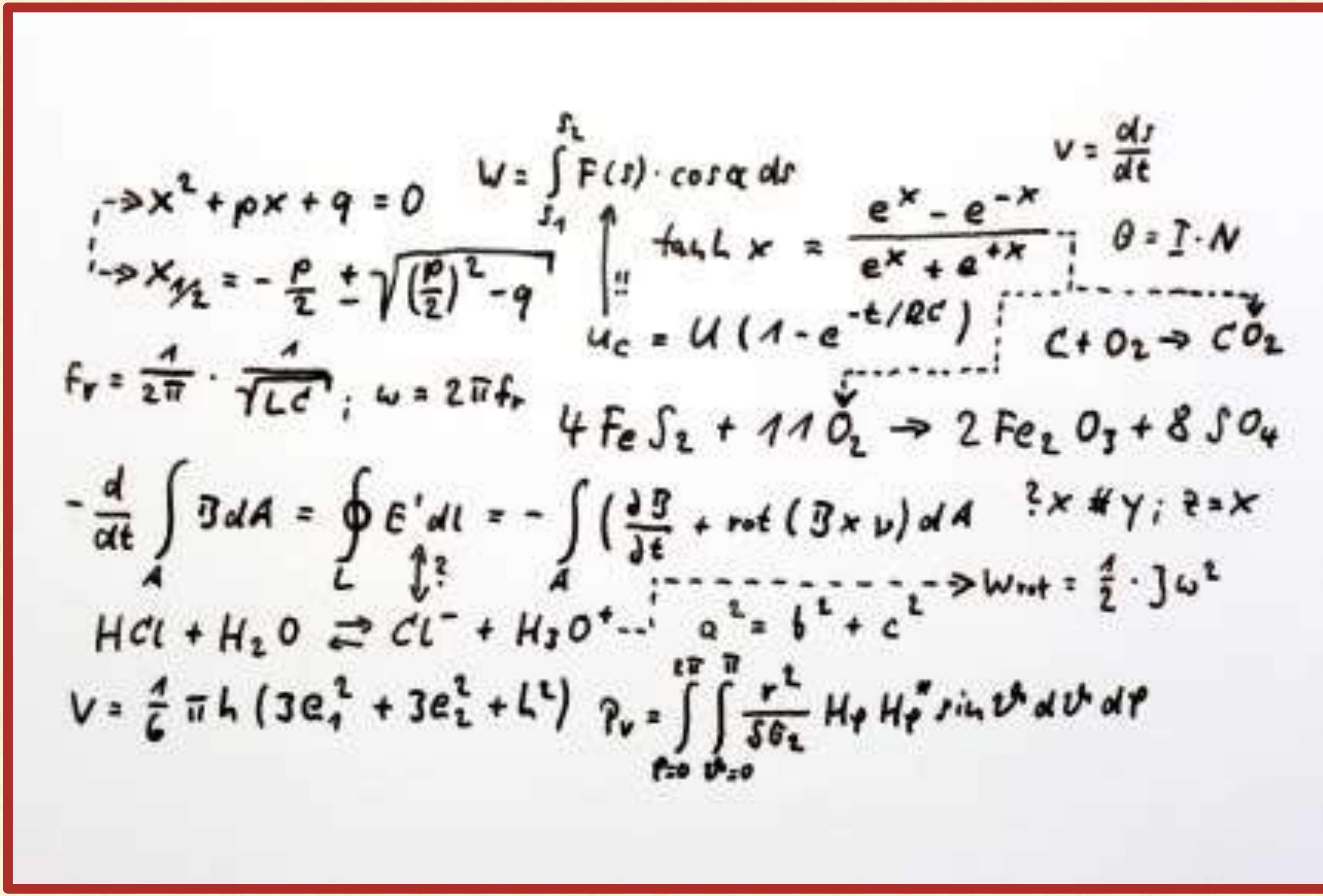


$x^2 + px + q = 0$
$W = \int_{s_1}^{s_2} F(s) \cdot \cos\alpha \, ds$
$v = \frac{ds}{dt}$
$x_{1/2} = -\frac{p}{2} \pm \sqrt{\left(\frac{p}{2}\right)^2 - q}$
$\tanh x = \frac{e^x - e^{-x}}{e^x + e^{+x}}$
$\Theta = I \cdot N$
$u_C = U(1 - e^{-t/RC})$
$C + O_2 \rightarrow CO_2$
$f_r = \frac{1}{2\pi} \cdot \frac{1}{\sqrt{LC}}; \omega = 2\pi f_r$
$4 FeS_2 + 11 O_2 \rightarrow 2 Fe_2O_3 + 8 SO_4$
$-\frac{d}{dt} \int_A B \, dA = \oint_L E' \, dl = -\int_A \left(\frac{\partial B}{\partial t} + rot(B \times v)\right) dA$
$x \neq y; z = x$
$W_{rot} = \frac{1}{2} \cdot J\omega^2$
$HCl + H_2O \rightleftarrows Cl^- + H_3O^+$
$a^2 = b^2 + c^2$
$V = \frac{1}{6}\pi h (3e_1^2 + 3e_2^2 + h^2)$
$P_v = \int_{\varphi=0}^{2\pi} \int_{\vartheta=0}^{\pi} \frac{r^2}{SG_2} H_\varphi H_\varphi^* \sin\vartheta \, d\vartheta \, d\varphi$

CT Dose is Important

2012 California CT Regulations

Radiation Dose Information (CTDIvol, DLP) required in patient report.

"Those who don't study history are doomed to repeat it. Yet those who *do* study history are doomed to stand by helplessly while everyone else repeats it."

WA State Draft CT Regulations

The registrant shall:

- (a) **Establish a procedure to record and retrieve estimated patient dose(DLP) from every CT procedure performed.**
- (b) **Provide estimated patient dose(DLP) within ten business days of a patient request.**
- (c) Send each CT procedure and protocol page that lists the technical factors and estimated patient dose electronically to the Picture Archiving and Communications System, also known as PACS.

CT DOSE METRICS

"CTDIvol…(along with dose-length product, [DLP]) is reported in the dose page of each patient CT study. With more patients interested in radiation dose delivered by CT and other medical imaging procedures, requests to get dose information are common, but unfortunately, the dose metrics that are readily available are often misunderstood."

J. Anthony Seibert, JACR, March 2014

Lee, et al.
Survey of Dose/Risk Awareness

- Percentage surveyed who believe that CT exams entailed an increased cancer risk:
  - **Radiologists: 47%**
  - **ED Physicians: 9%**
  - **Patients: 3%**
- All patients and most ED physicians and radiologists were unable to accurately estimate the dose for one CT scan compared with that for one chest radiograph.

http://radiology.rsnajnls.org/cgi/content/full/2312030767v1

Educating the Practitioner
The Reality

"You cannot make it feasible for all of us to remember the radiation dose of an examination, since this is changeable and we have other things to do than replace minimally useful numbers in our memory with new, improved, and minimally useful numbers." (GP physician)

CT "In the News"

SEATTLE PI 11/29/07

Warning on cancer risk from CT scans

THE ASSOCIATED PRESS

Millions of Americans, especially children, are needlessly getting dangerous radiation from "super X-rays" that raise the risk of cancer and are increasingly used to diagnose medical problems, a report warns.

In a few decades, as many as 2 percent of all cancers in the United States might be caused by radiation from CT scans given now, the authors say.

Some experts say that estimate is overly alarming. But they agree with the need to curb these tests, particularly in children, who are more susceptible to radiation and more likely to develop cancer from it.

"There are some serious concerns about the methodology used," but the authors "have brought to attention some real serious potential public health issues," said Dr. Arl Van Moore, head of the American College of Radiology's board of chancellors.

The risk from a single CT, or computed tomography, scan is small. But "we are very concerned about the built-up public health risk over a long period of time," said Eric Hall, who wrote the report with fellow Columbia University medical physicist David Brenner.

The average American's total radiation exposure has nearly doubled since 1980, largely because of CT scans. Medical radiation now accounts for more than half of the population's total exposure; it used to be just one-sixth.

The report, in the New England Journal of Medicine, was paid for by federal grants.

“Informing” the Public

- Licensed physician and surgeon
- Interviews by Today Show, CNN, Dr. Oz, etc..

Informing the Public (cont.)

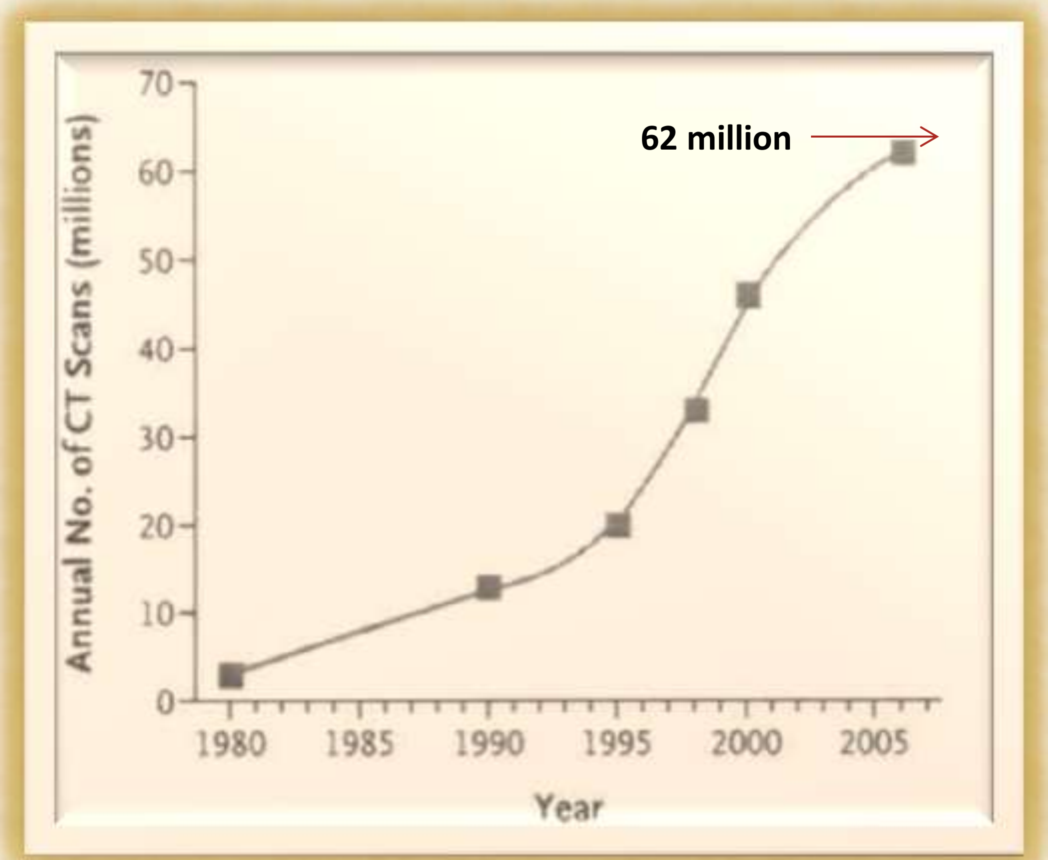
- "**explosion** in unnecessary CT scans…150,000 Americans are facing **horrific** deaths from CT scan-induced cancers"
- "Studies have recently found that **radiation doses from CT scans tend to be higher than reported**"
- "The difference between a routine CT scan and a death sentence is as simple as a computer error causing you to be **blasted** with errant beams of radiation, leaving you in **unspeakable pain**, or worse.

Goals

- Defining the Problem(The “Perfect Storm”)
- Dose Basics: Understanding what “Dose” means and what it doesn’t mean
- Acquiring literacy in informing the patient/public on “CT Dose”

Brian has a rendezvous with destiny.

SKYROCKETING USE OF CT IN U.S.



Currently accounts for ~70% of all medical x-ray exposure in U.S.

Brenner, NEJM, November 2007

Radiation Dose Comparison

Diagnostic Procedure	Typical Effective Dose (mSv)[1]	Number of Chest X rays (PA film) for Equivalent Effective Dose[2]	Time Period for Equivalent Effective Dose from Natural Background Radiation[3]
Chest x ray (PA film)	0.02	1	2.4 days
Skull x ray	0.07	4	8.5 days
Lumbar spine	1.3	65	158 days
I.V. urogram	2.5	125	304 days
Upper G.I. exam	3.0	150	1.0 year
Barium enema	7.0	350	2.3 years
CT head	2.0	100	243 days
CT abdomen	10.0	500	3.3 years

year in the United States

CT as a High Dose Modality

1 Conventional Diagnostic Chest CT

(20 to 50 mGy)

=10 to 25 2-view mammograms

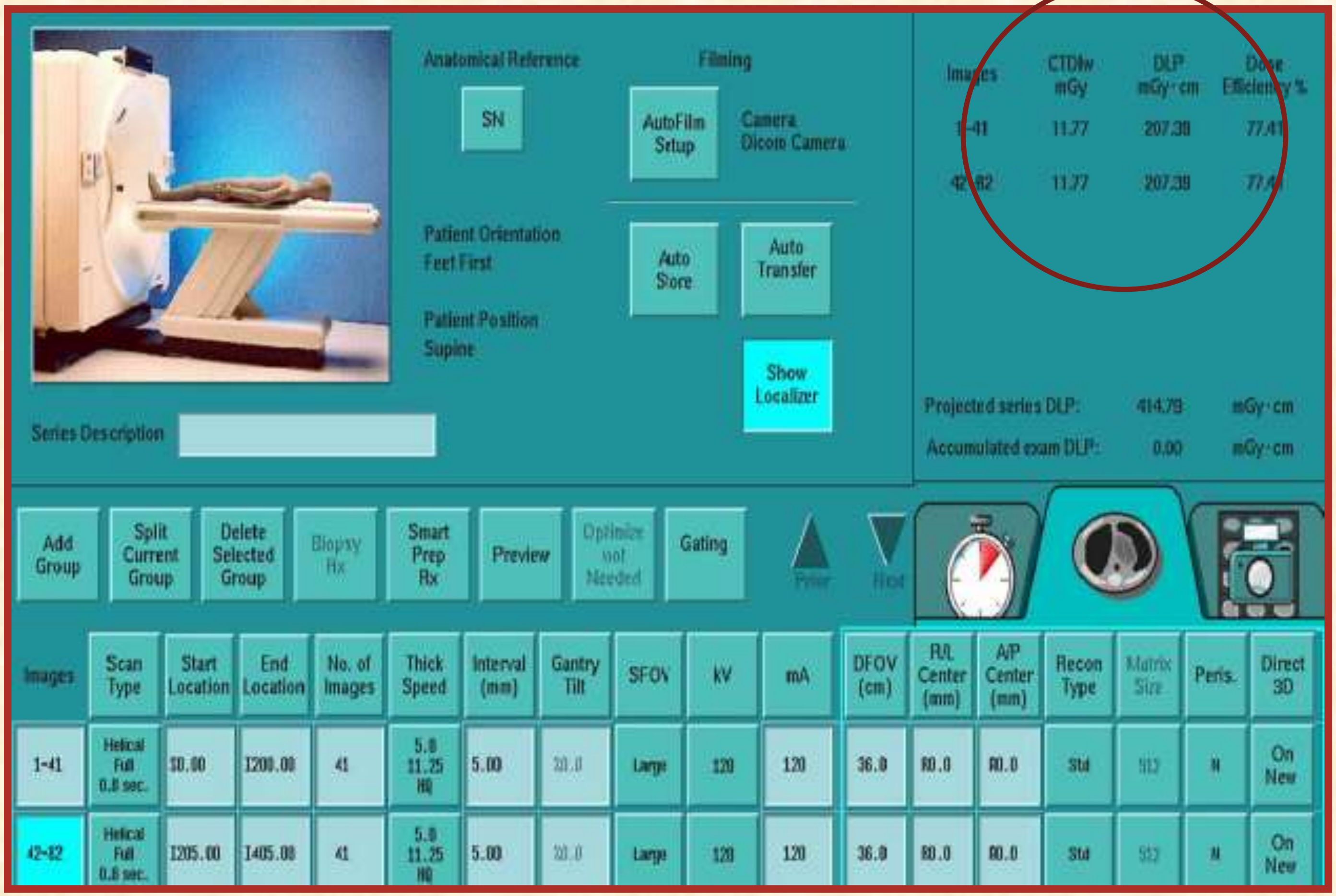
=100 to 400 chest radiographs

Parker, et al. (AJR:185, November 2005)

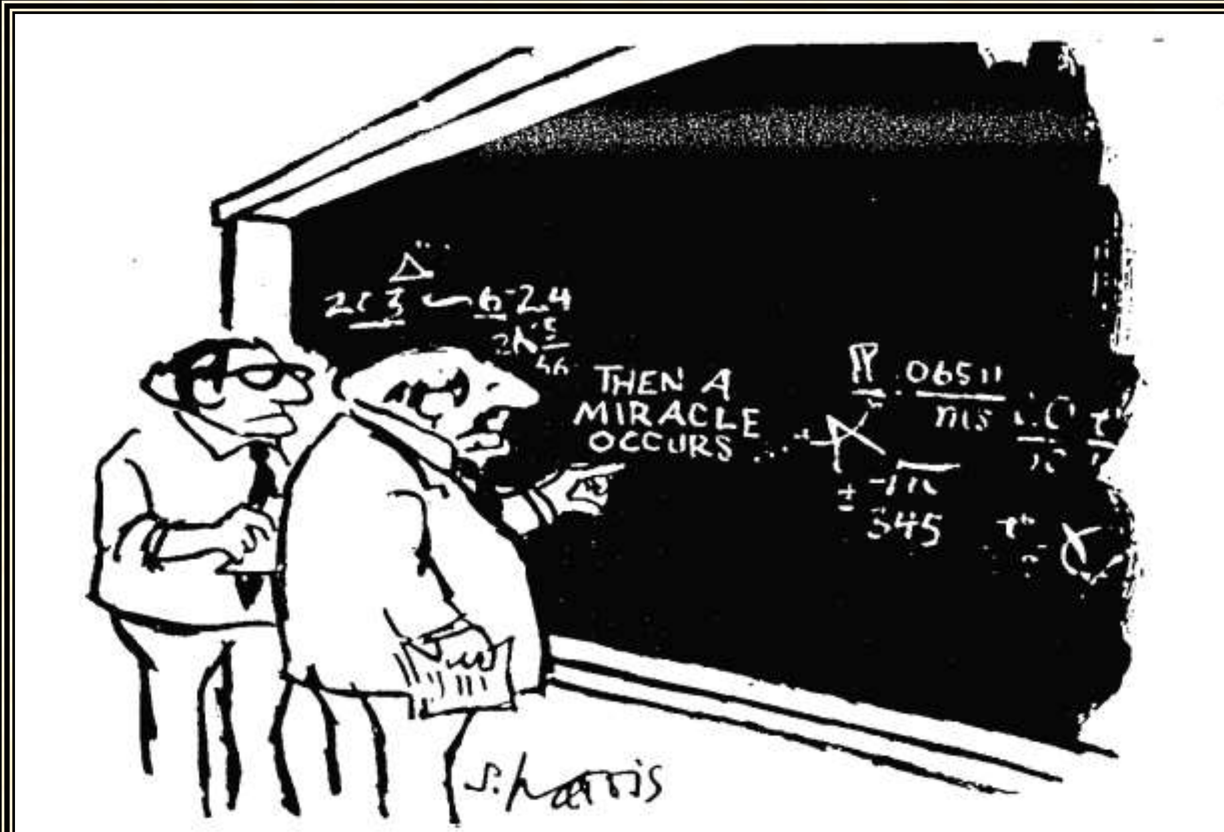
Mad River Hospital, 2008

Cedars Sinai 2009

CTDIvol and DLP



Calculating CT Dose and Risk



"I think you should be more explicit here in step two."

A Complex Modality

SSDE

Pitch

Beam Filtration

mAs

kVp

dose length product

$CTDI_w$

$CTDI_{vol}$

$CTDI_{100}$

ASIR

# of slices

Overbeaming

Scanning geometry

Detector configuration

Scan Length

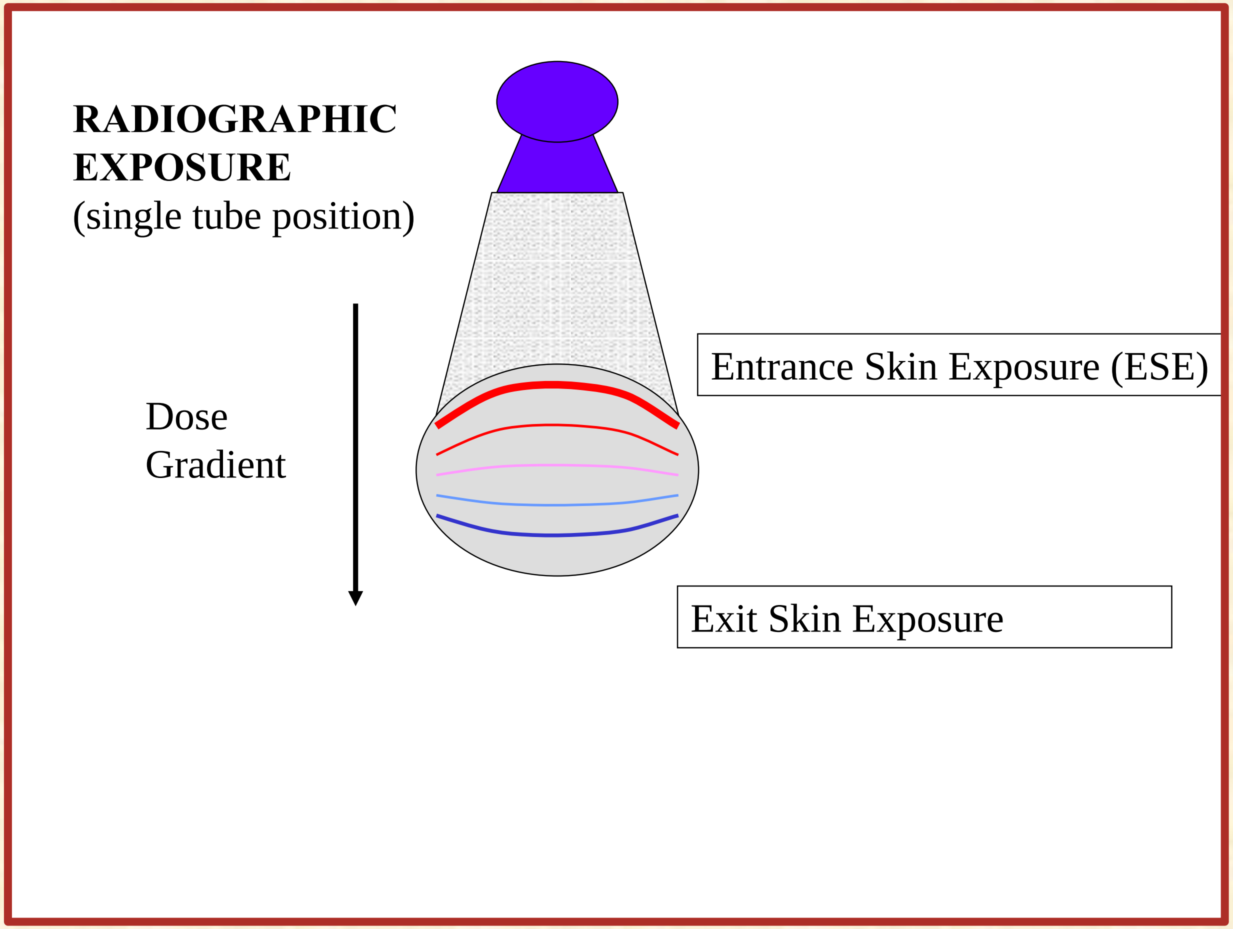
AEC Modulation

Scan spacing

Brief Unit Review

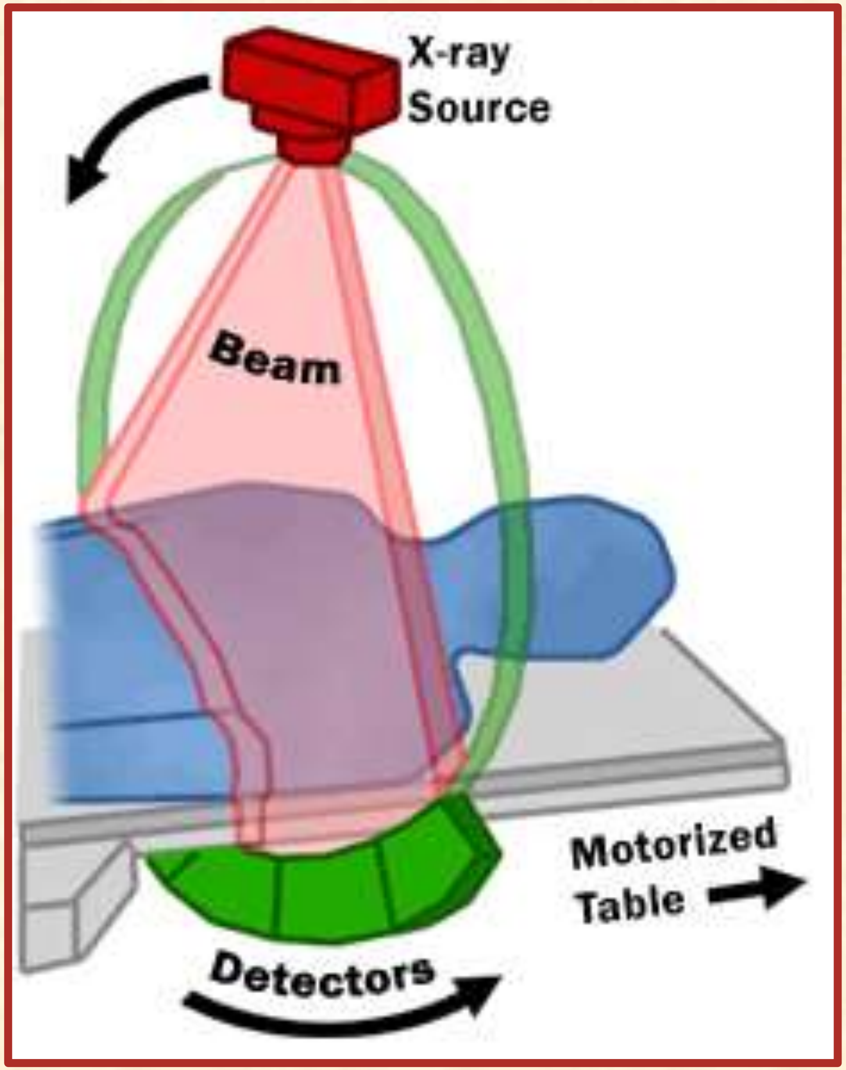
- R (Roentgen) = Exposure in air
- mGy, Rad = Absorbed dose in tissue (ergs/gram).
  - 1 mGy = 100 mrad
- mSv, Rem = Effective Dose equivalent
  - 1mSv = 100 mrem
  - Equates absorbed dose to a whole-body risk.
  - Allows comparison between doses from different sources.
  - A weighted average of organ doses.

X-ray Dose Profile



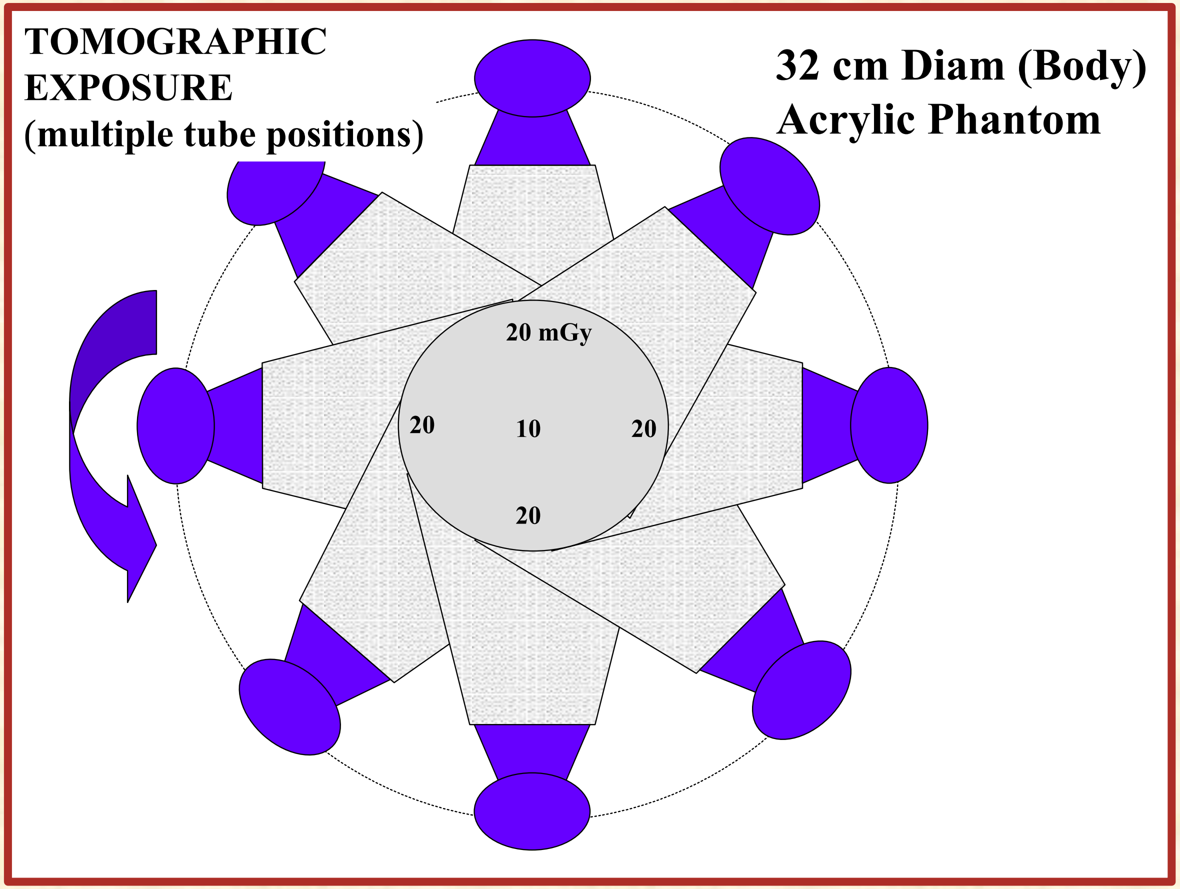
McNitt Gray AAPM, 2005

CT Dose Complexity



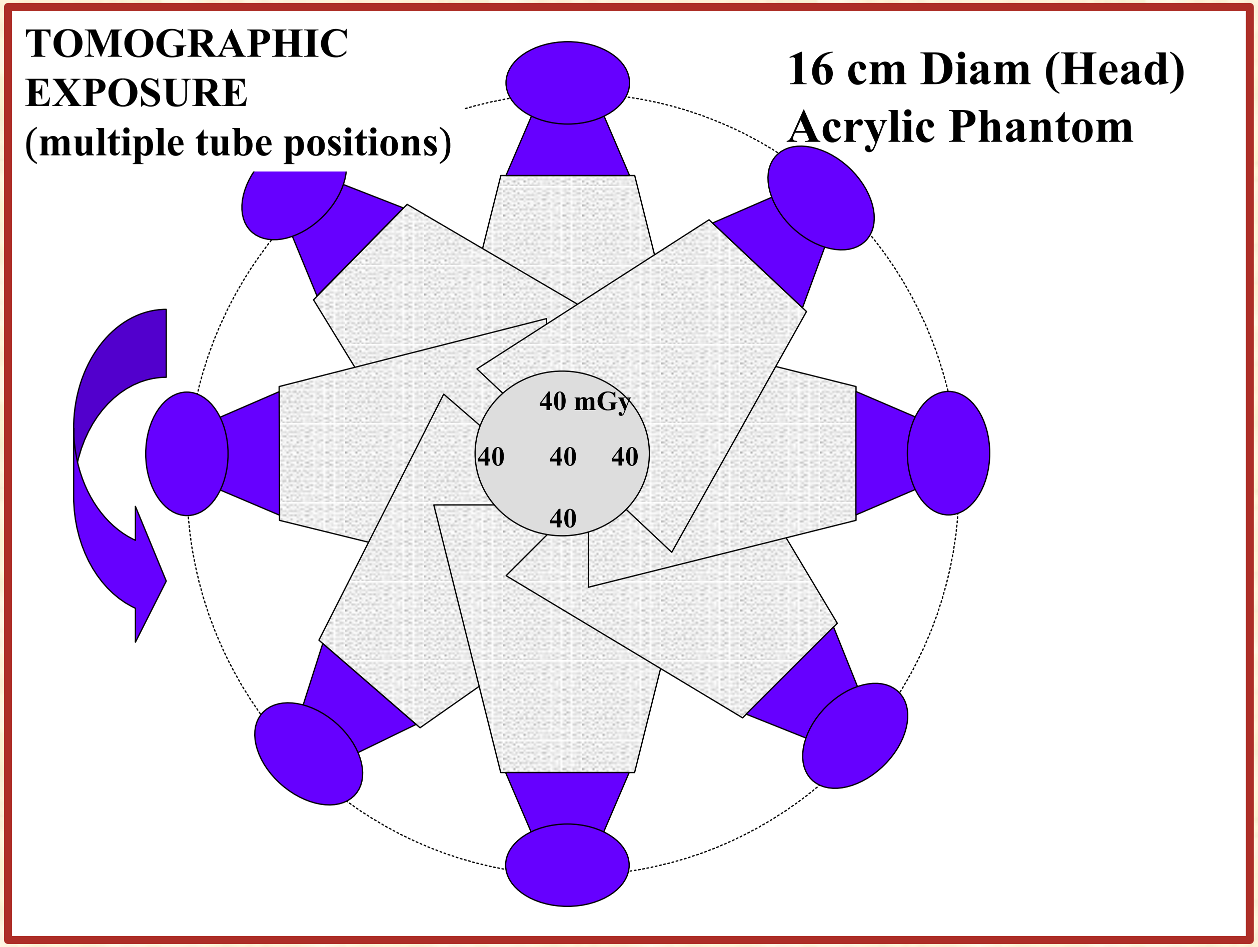
www.fda.gov

Adult Abdomen Exposure

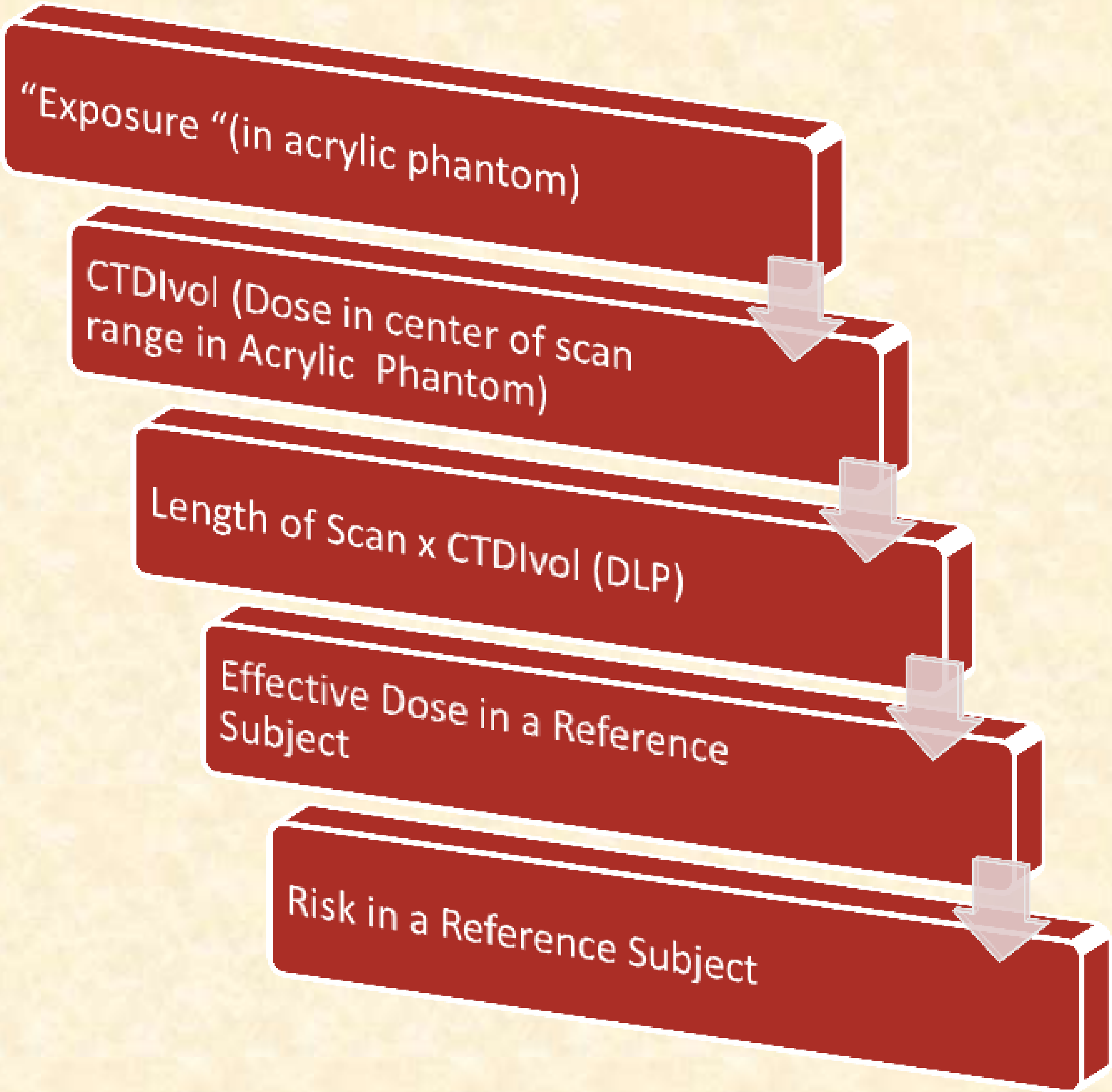


McNitt Gray AAPM, 2005

Head/Pediatric Abdomen



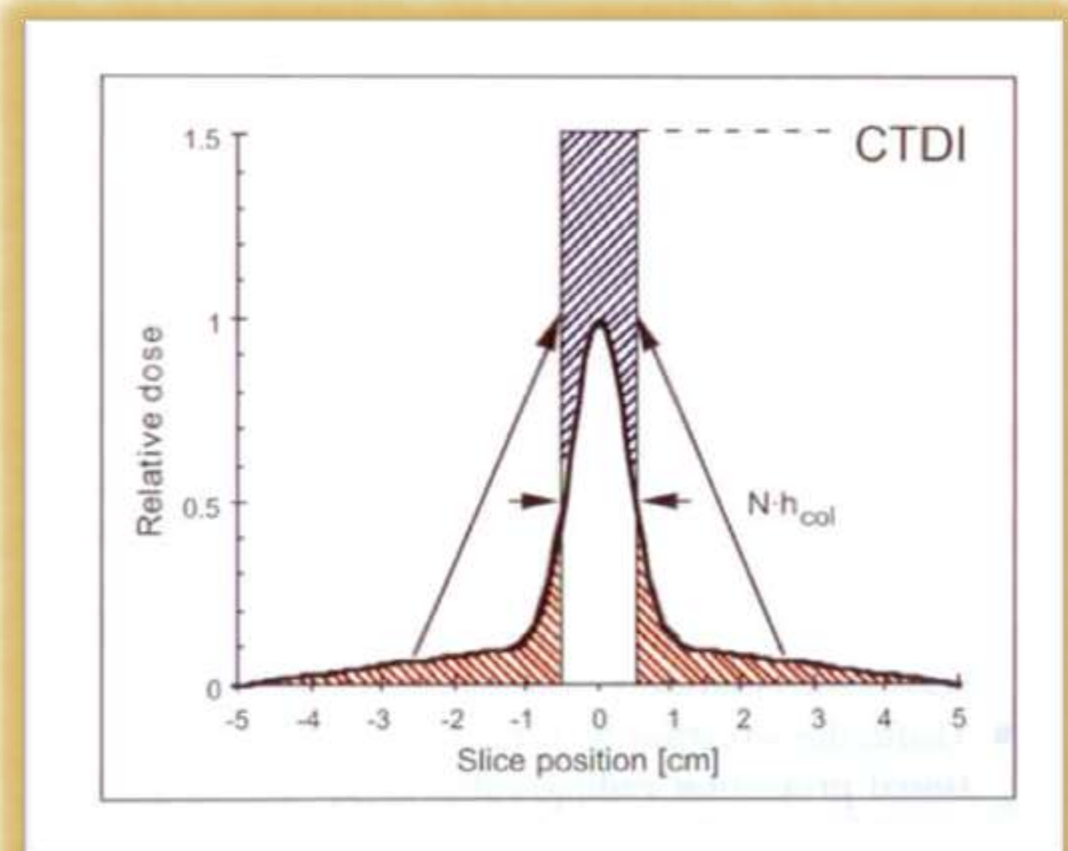
AAPM_SCC_2005_McNItt-Gray.pdf


"Exposure "(in acrylic phantom)
CTDIvol (Dose in center of scan range in Acrylic Phantom)
Length of Scan x CTDIvol (DLP)
Effective Dose in a Reference Subject
Risk in a Reference Subject

Dose Calculations

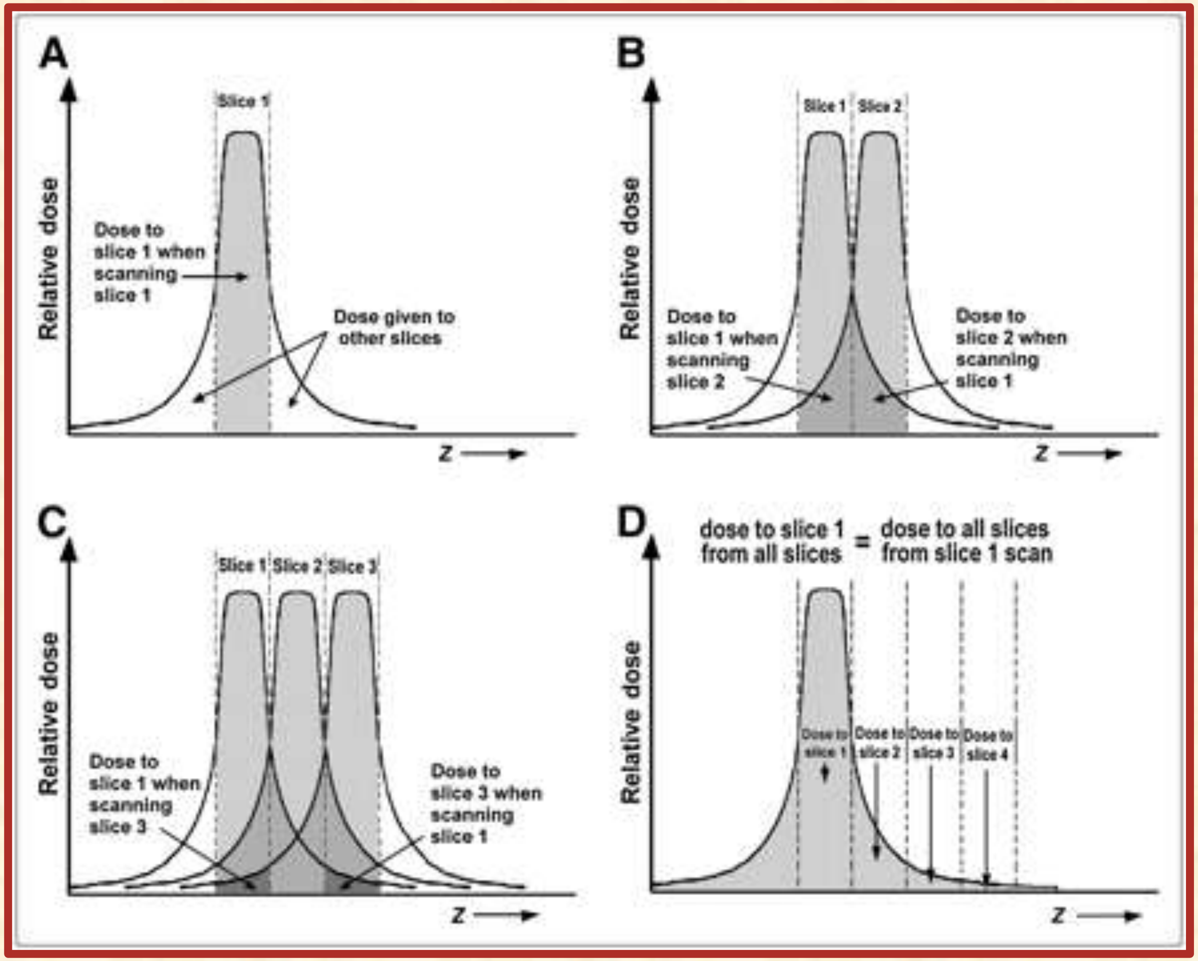
- CTDI:
  - Measured in 32 cm (adult abdomen, pediatric abdomen) and 16 cm (adult head, pediatric abdomen) acrylic phantoms.
  - Measured dose in a given slice plus dose in that slice from adjacent slices.
  - Measured at center and periphery (1 cm from surface) of phantom.
- $CTDI_w$
  - $= (1/3)CTDI_{center} + (2/3)CTDI_{periphery}$
  - Provides a weighted average of the central and peripheral contributions to dose in the scan plane.

CTDI-Computed Tomography Dose Index

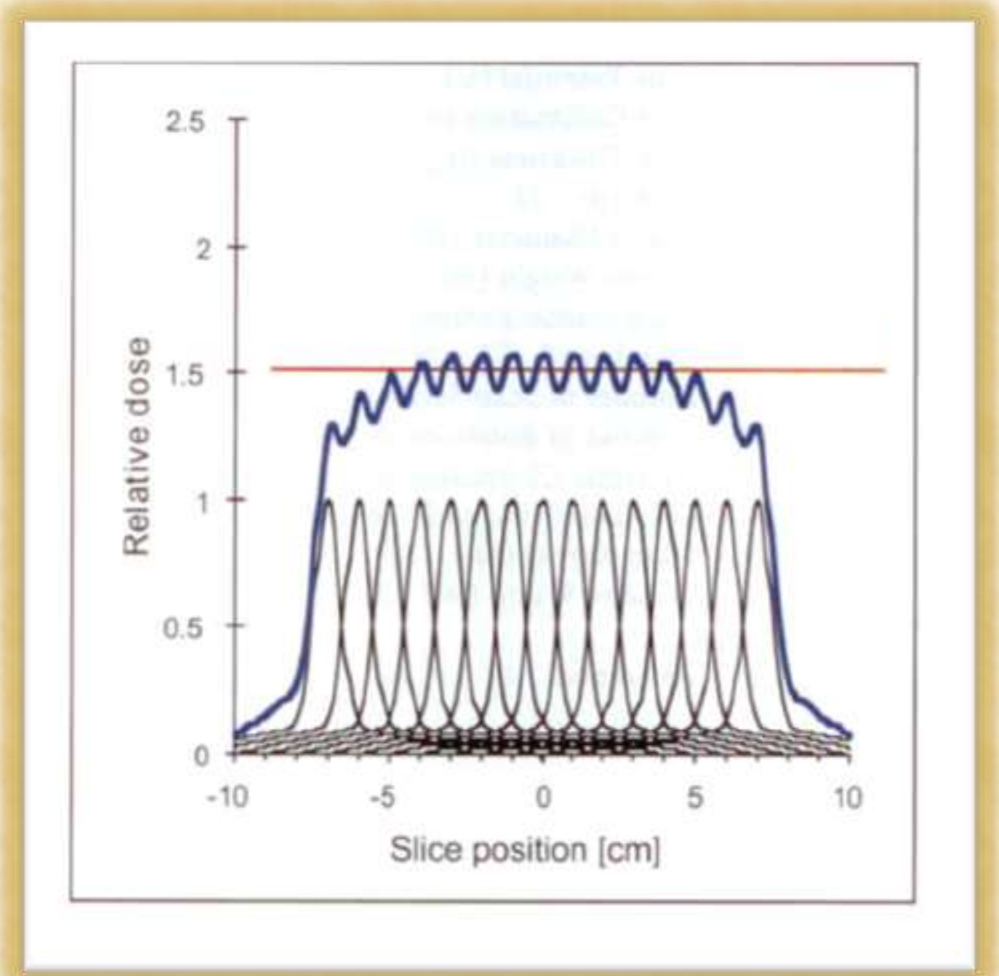


Tack, 2007

Dose contribution from adjacent slices

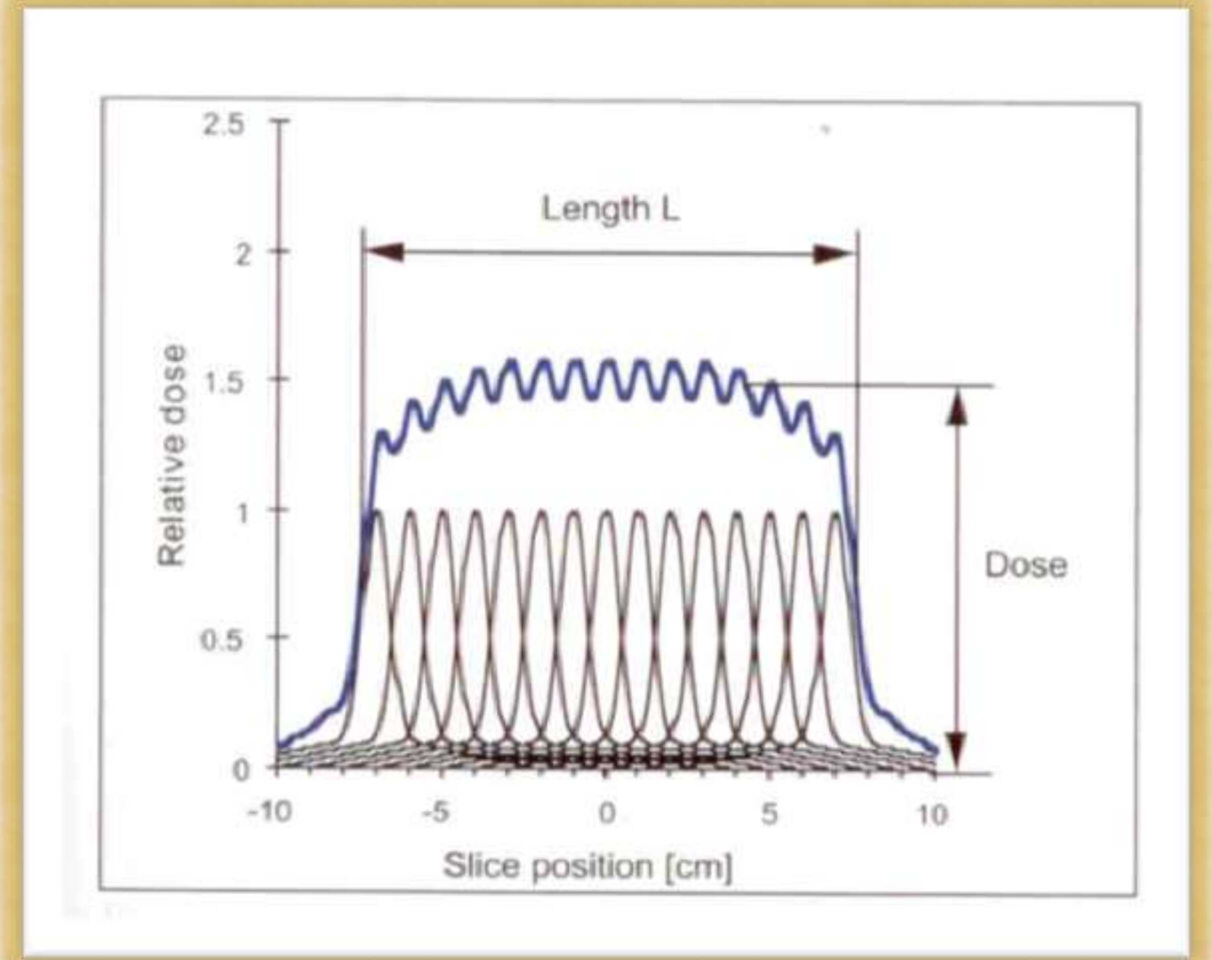


$CTDI_{vol} = CTDI_w/pitch$



Tack, 2007

DLP = Dose Length Product



DLP(mGy-cm)=$CTDI_{vol}$ x scan length

Tack, 2007

Dose Calculations (Cont.)

Eff. Dose (mSv) = DLP (mGy·cm) x CF (mSv/mGy·cm)

- DLP (Dose length Product)
  - $CTDI_{vol}$ x Scan Length (units = mGy·cm).
  - Provides absorbed dose in entire range of scan.
- Effective Dose (mSv, mrem)
  - Converts DLP (absorbed dose) into a quantity that expresses radiation risk to individual.
  - Sum of dose to individual organs x the weighting factors assigned to those organs.
  - Ex: Same DLP will lead to different effective dose for head and abdomen scans.

DLP to Effective Dose

DLP to Effective Dose Conversion Factors (mSv/mGy-cm)				
Age (Yrs)	Head	Neck	Chest	Abdomen/ Pelvis
0	0.011	0.017	0.039	0.049
1	0.007	0.012	0.026	0.030
5	0.004	0.011	0.018	0.020
10	0.003	0.008	0.013	0.015
15	--	--	--	0.015
Adult	0.002	0.006	0.014	0.015

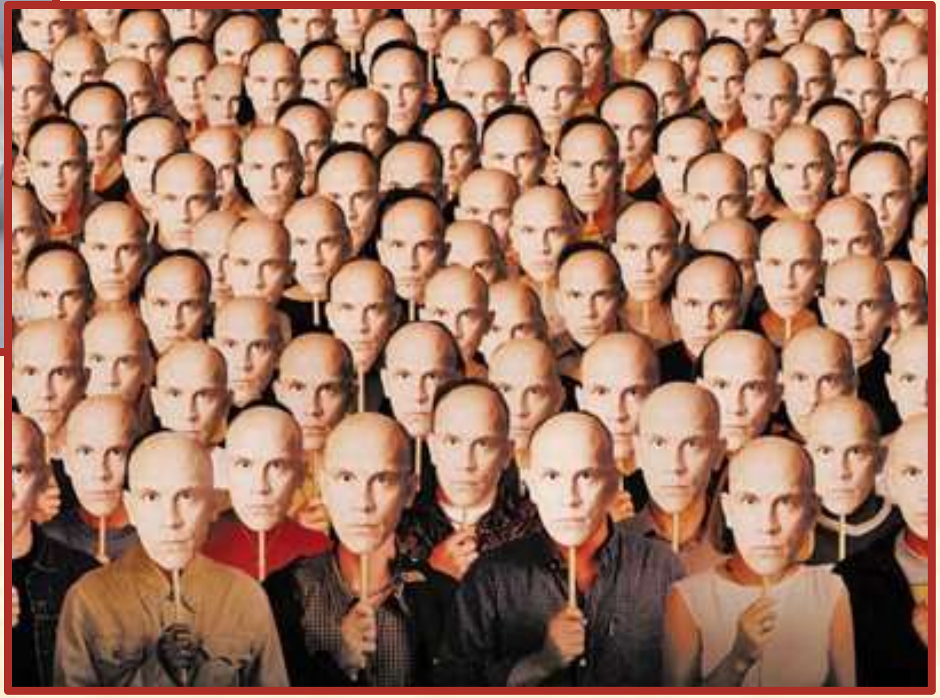
Shrimpton, 2005

Anatomical Reference
SN
Filming
AutoFilm Setup
Camera Dicom Camera
Patient Orientation Feet First
Patient Position Supine
Auto Store
Auto Transfer
Show Localizer
Series Description
Images
CTDIw mGy
DLP mGy·cm
Dose Efficiency %
1-41 11.77 207.39 77.41
42-82 11.77 207.39 77.41
Projected series DLP: 414.79 mGy·cm
Accumulated exam DLP: 0.00 mGy·cm
Add Group
Split Current Group
Delete Selected Group
Biopsy Rx
Smart Prep Rx
Preview
Optimize not Needed
Gating
Prior
Next
Images
Scan Type
Start Location
End Location
No. of Images
Thick Speed
Interval (mm)
Gantry Tilt
SFOV
kV
mA
DFOV (cm)
R/L Center (mm)
A/P Center (mm)
Recon Type
Matrix Size
Peris.
Direct 3D

Dose Estimations - Caveats

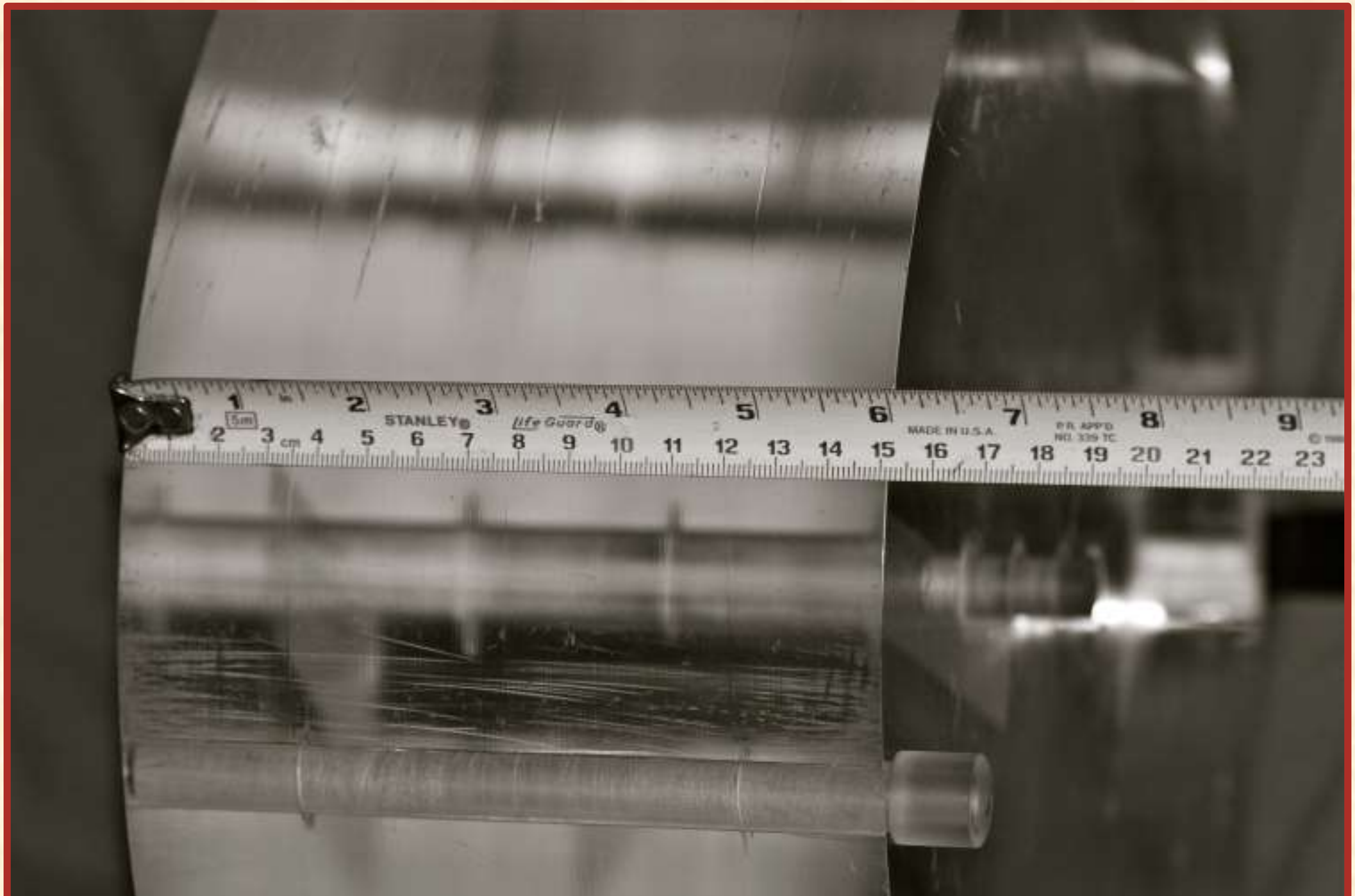
- Dose calculations are based on a reference phantom only--Individual doses/risks may vary greatly.
  – Phantom
    - Size, shape
    - Acrylic composition
  – Patient/phantom centering: can dramatically influence resultant dose.
  – mA modulation changes dose to different regions.
  – Risk coefficients depend on age, anatomy exposed, other confounding factors.

The Dose "Ideal"

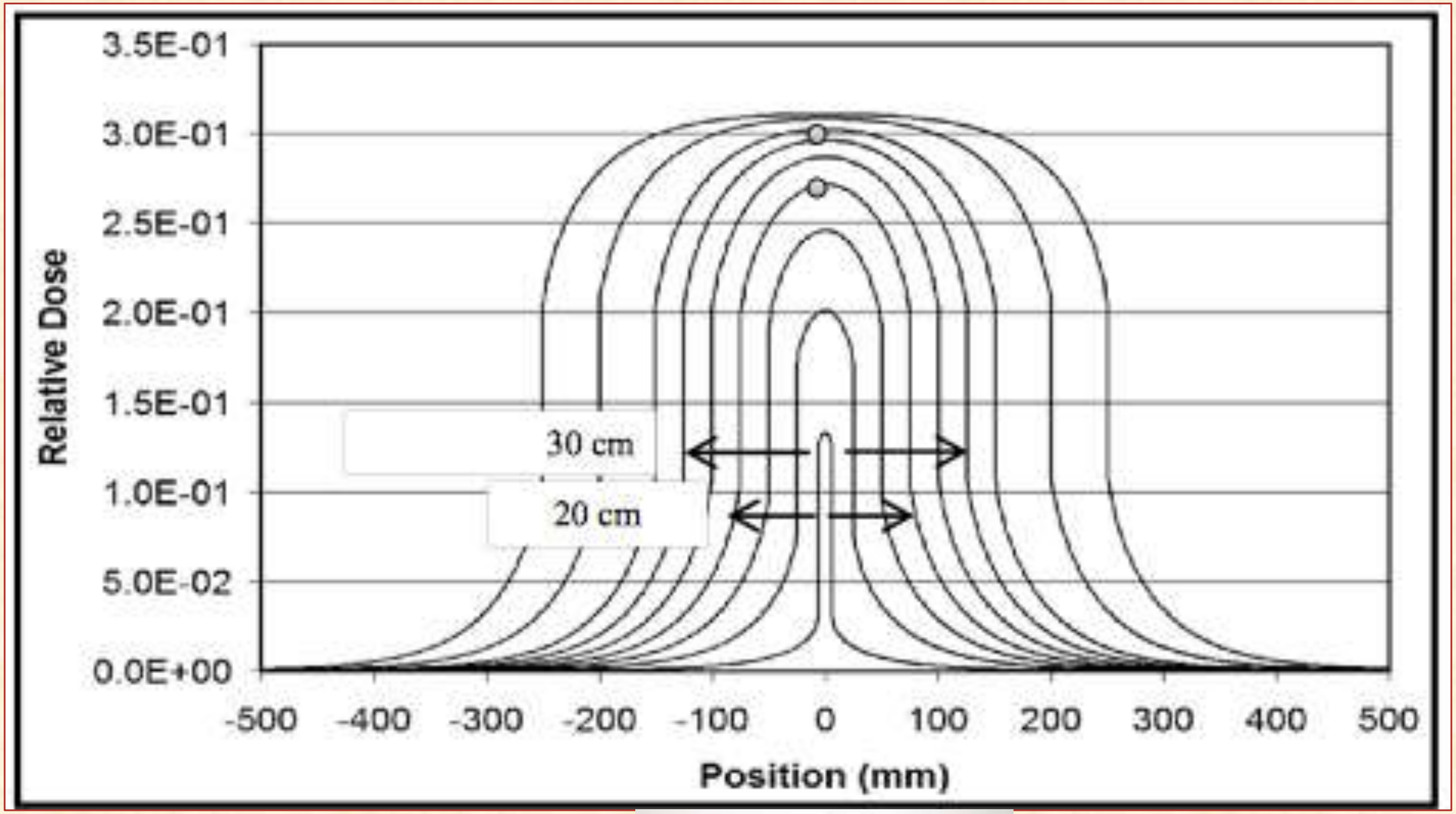


The Dose Reality

Phantom Length (15 cm)

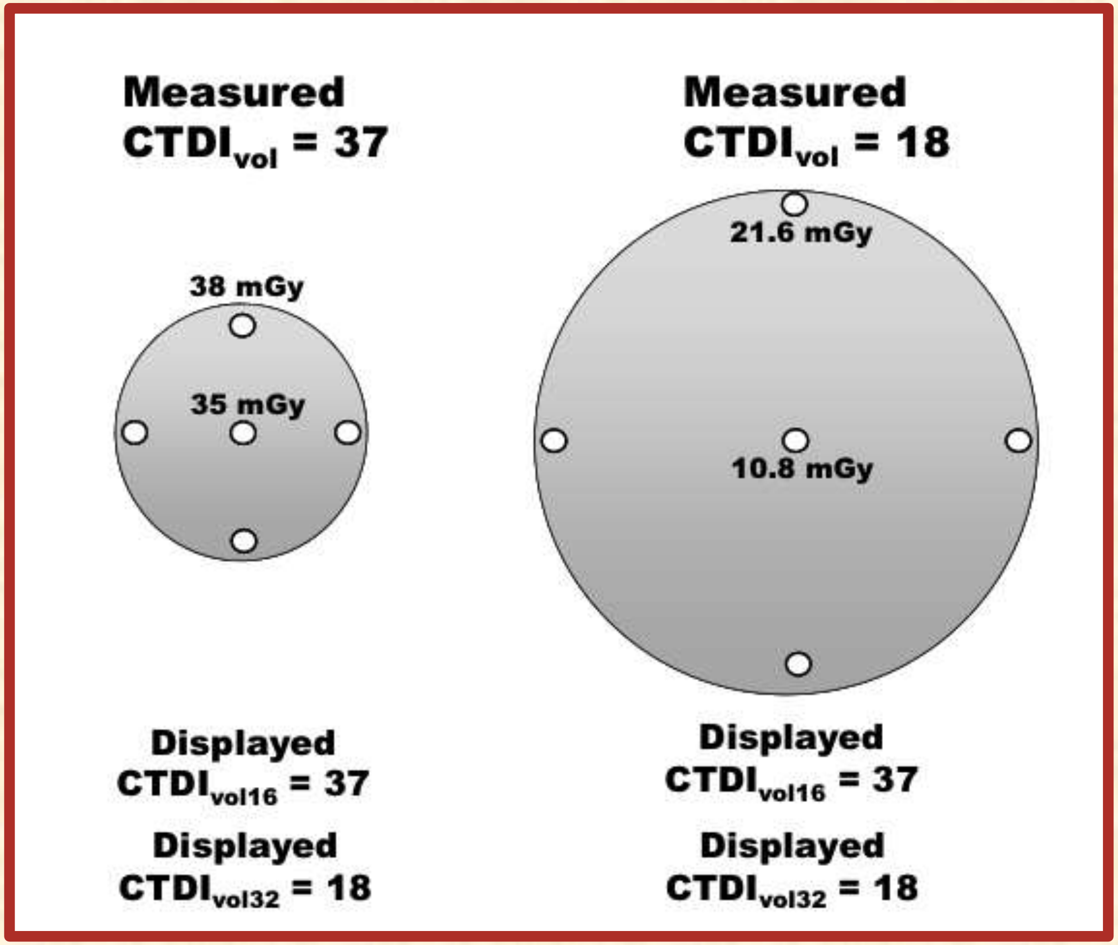


CTDIvol and Dose "Tails"



J. Boone, UC-Davis Medical Center

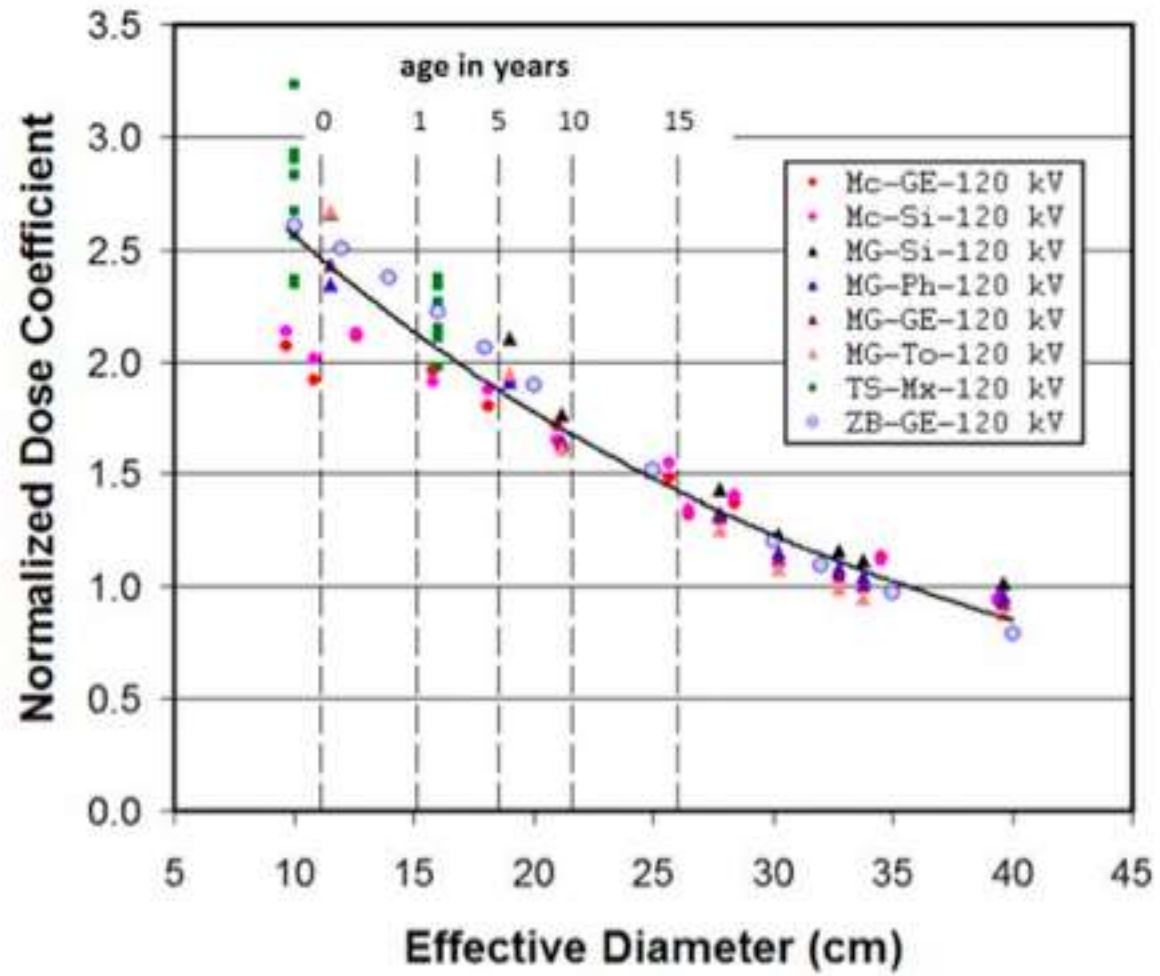
Problem with Displayed/Reported Dose



Vendor Phantom Selections

- Vary for pediatric abdomen scans
  - Siemens, Philips use 32 cm phantoms
  - G.E., Toshiba, Hitachi use 16 cm phantoms
- Can result in significant under or over-estimations of CTDIvol (and correspondingly DLP)
- Currently no national nor international standard on which phantom to use.

Dose vs. Diameter Abdomen 32cm



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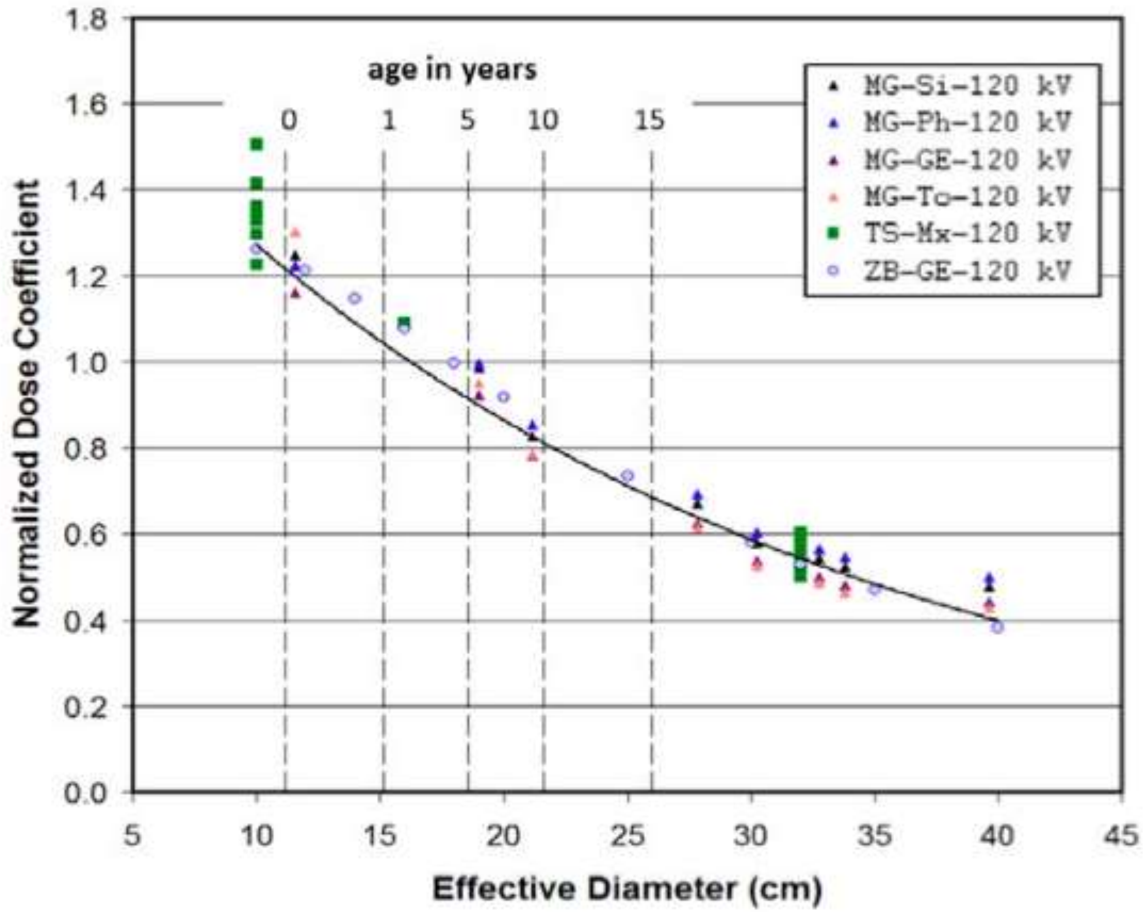
Dose vs. Diameter Abdomen 16cm



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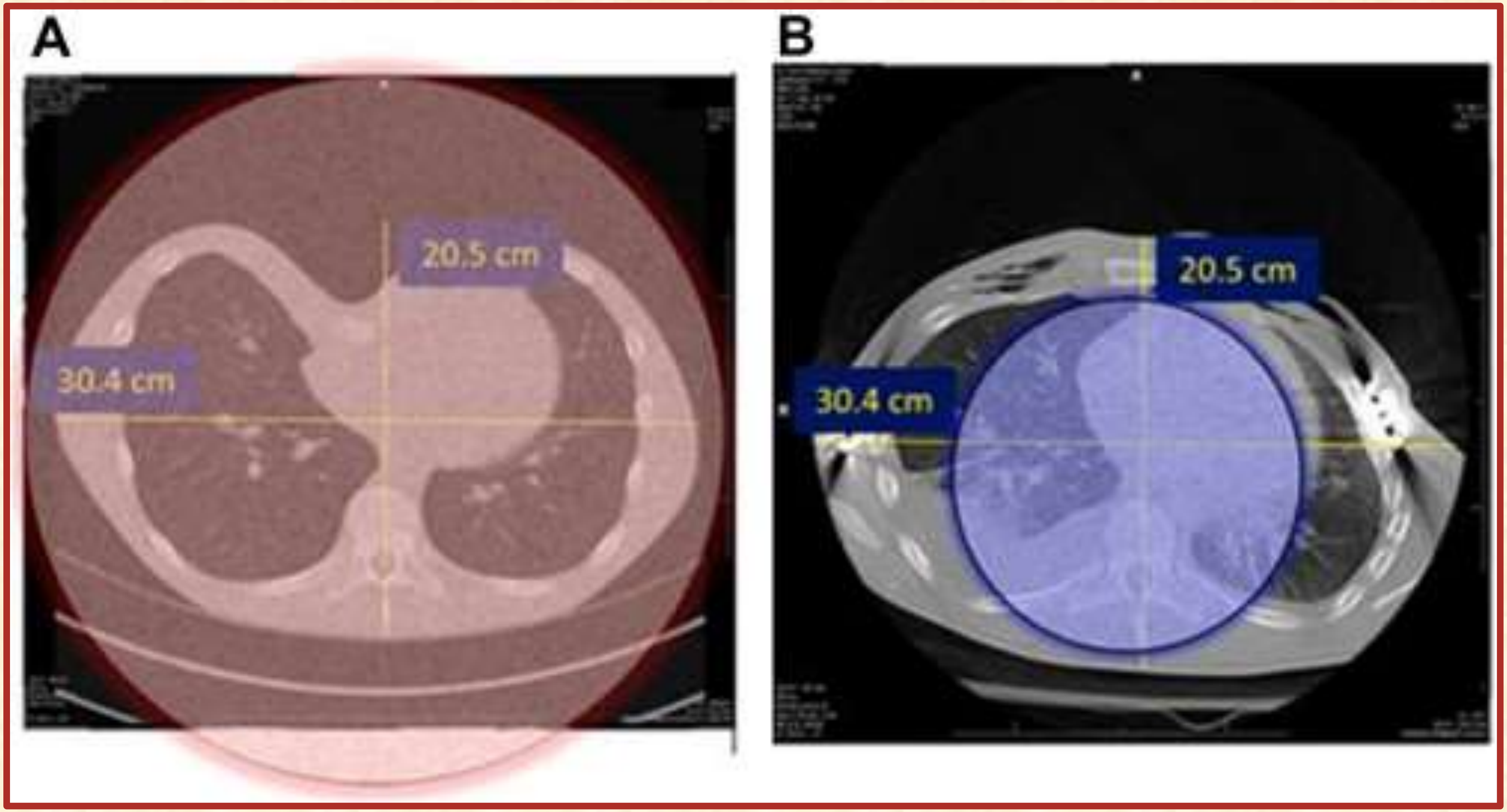
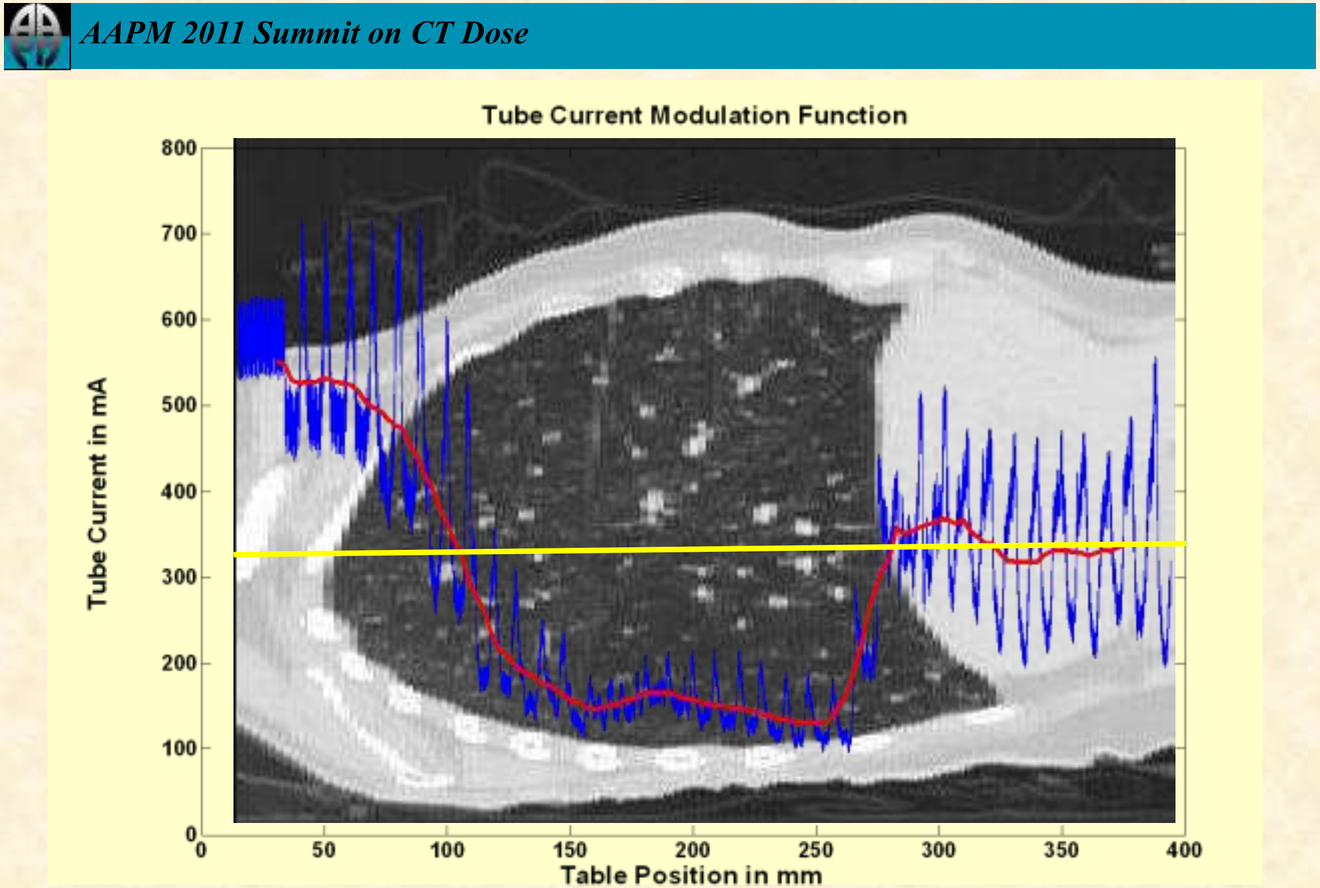
JACR March 2014-Seibert



Actual mAs vs. displayed mAs



Displayed CTDIvol and DLP

ARE NOT PATIENT DOSE!!!!

Anthony Seibert, JACR 2014

"Many nuances and details in the reporting of radiation dose can lead to significant overestimates or underestimates, and corresponding misinterpretation can be potentially detrimental to the patient, patient's parents, and even to the institution. At the minimum, a size-specific dose conversion using SSDE methods should be applied to the CTDIvol reported values before release, if at all possible."

SSDE (Size Specific Dose Estimates)

- The “latest, greatest” CT dose metric (May 2011)
- Accounts for differences in patient size
  - Effective Diameter based on patient AP and Lateral dimensions
- Accounts for differences in phantom (16 or 32 cm)
- Does not account for missed dose “tails”
- Still a dose “estimate”, but a much better one.

SSDE (cont.)

Table 1A

Lat+AP Dim (cm)	Effective Dia (cm)	Conversion Factor
16	7.7	2.79
18	8.7	2.69
20	9.7	2.59
22	10.7	2.50
24	11.7	2.41
26	12.7	2.32
28	13.7	2.24
30	14.7	2.16
32	15.7	2.08
34	16.7	2.01
36	17.6	1.94
38	18.6	1.87
40	19.6	1.80

Table 1B

Lateral Dim (cm)	Effective Dia (cm)	Conversion Factor
8	9.2	2.65
9	9.7	2.60
10	10.2	2.55
11	10.7	2.50
12	11.3	2.45
13	11.8	2.40
14	12.4	2.35
15	13.1	2.29
16	13.7	2.24
17	14.3	2.19
18	15.0	2.13
19	15.7	2.08
20	16.4	2.03

Table 1C

AP Dim (cm)	Effective Dia (cm)	Conversion Factor
8	8.8	2.68
9	10.2	2.55
10	11.6	2.42
11	13.0	2.30
12	14.4	2.18
13	15.7	2.08
14	17.0	1.98
15	18.3	1.89
16	19.6	1.81
17	20.8	1.73
18	22.0	1.65
19	23.2	1.58
20	24.3	1.52

Table 1D

Effective Dia (cm)	Conversion Factor
8	2.76
9	2.66
10	2.57
11	2.47
12	2.38
13	2.30
14	2.22
15	2.14
16	2.06
17	1.98
18	1.91
19	1.84
20	1.78

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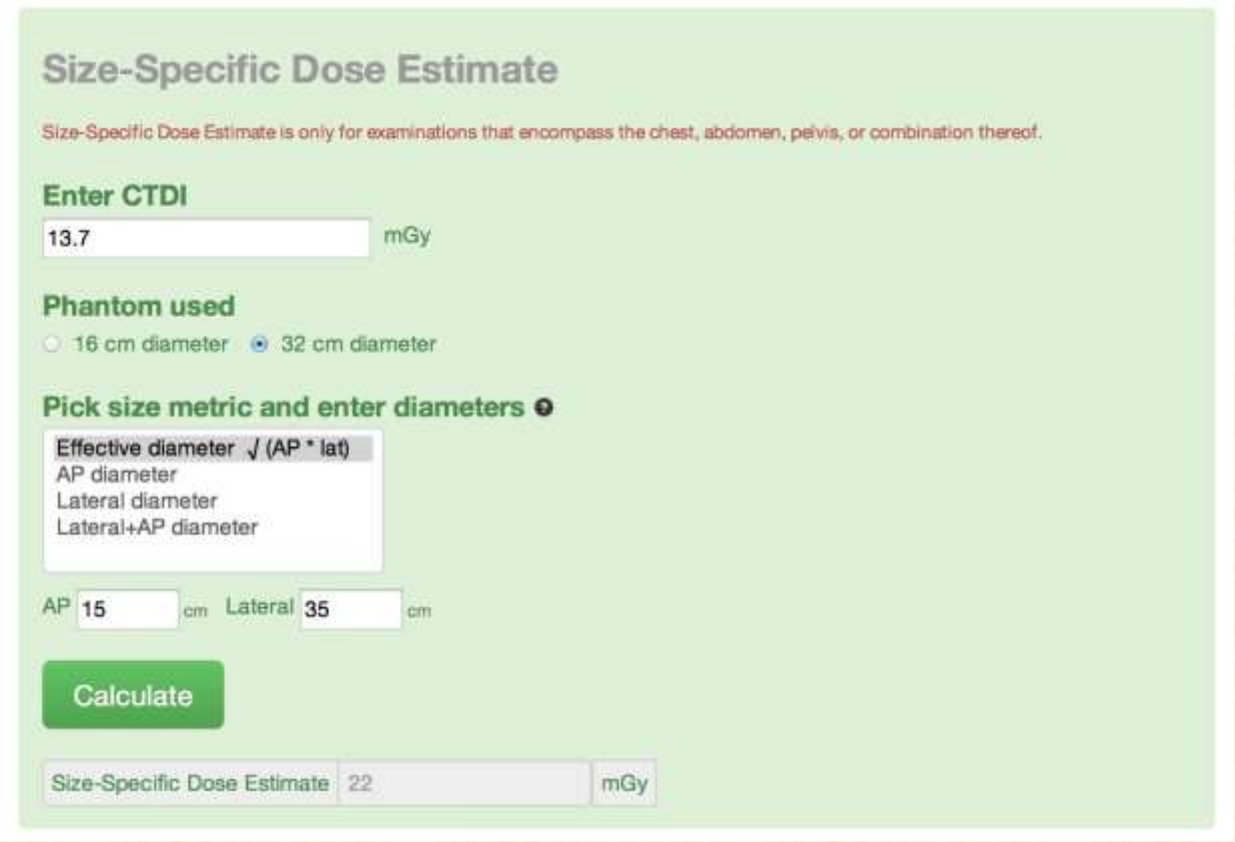
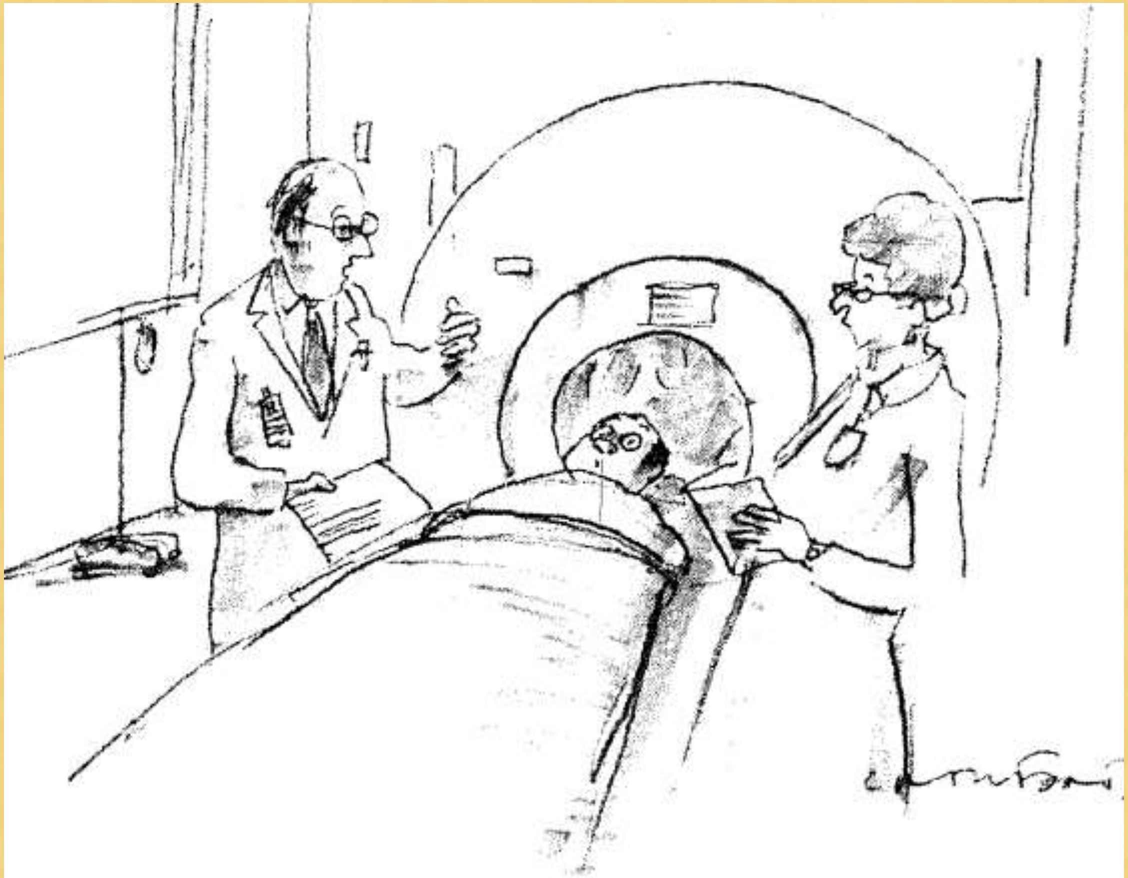
Seibert, JACR, March 2014

SSDE Sample



http://www.radiation-dose.com

Optimizing CT Scan Parameters



"Forty minutes at three hundred and fifty degrees should do it, Miriam, but don't forget to baste continuously."

CTDIvol Review

- Does NOT represent patient dose.
- Does NOT take patient size into account.
- Should NOT be used to estimate effective dose or cancer risk for any individual patient.
- Can significantly underestimate or overestimate actual patient dose.

CTDIvol

- Reflects the average dose to a cylindrical phantom (16 or 32 cm) in the central region of a series of scans.
- Enables users to gauge radiation emitted by scanner
- Enables users to compare radiation output between different scan protocols or scanners.

CTDIvol

- Enables users to compare output of standard reference exams to published standards and regulatory limits (e.g., ACR).
- Enables users to assess the dose impact of changes in protocols.

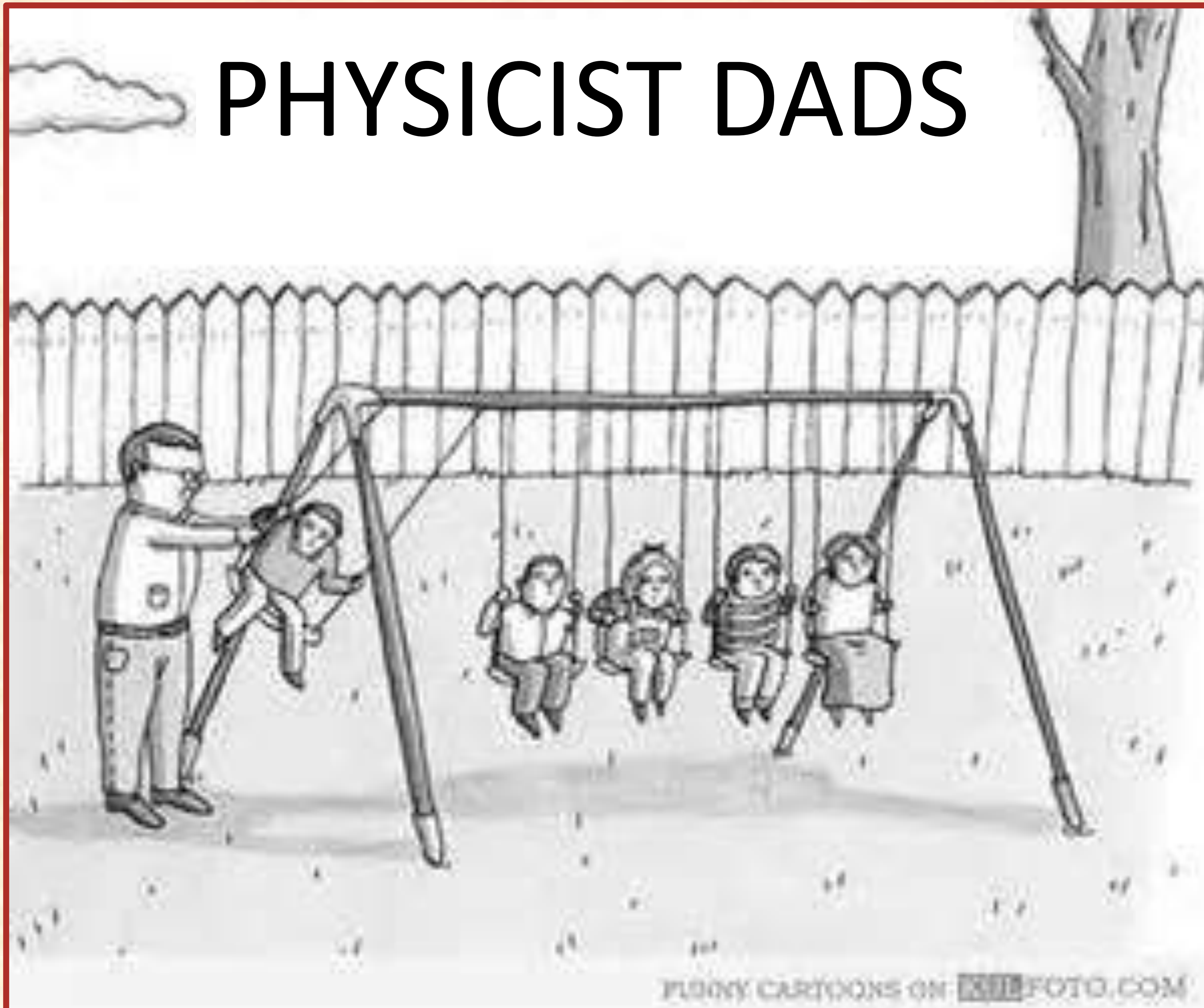
Available Resources

- ACR Dose Registry
  - Allows facilities to compare dose to other facilities
- Proliferation of Published DRLs
- ACR Image Quality Reference Guide and published Dose limits for standard scans
- AAPM published protocols many several vendors and scan types.
- Applications specialists/users groups

Technology is dominated by two types of people: those who understand what they do not manage, and those who manage what they do not understand.

Putt's Law

PHYSICIST DADS




Thank You!!