Assessing Radiation Dose: How to Do It Right

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CT –Specific Dose Definitions

- CTDI and its cousins
  - $CTDI_{100}$
  - $CTDI_{w}$- weighted
  - $CTDI_{vol}$ -> DLP -> Effective Dose
- Dose Reports
- Future Dose Metrics
  - TG 204
  - TG 111/200/ICRU
  - IEC

(CTDI) – defined

- CTDI Represents
  - **Average dose** along the z direction
  - at a given **point (x,y)** in the scan plane
  - over the **central scan of a series of scans**
  - when the series consists of a **large number of scans**
  - **separated by the nominal beam width** (contiguous scanning)

CTDI Phantoms

- Body (32 cm diam), Head (16 cm diam)
- Holes in center and at 1 cm below surface
- 10 cm diameter also available in some models

$CTDI_{100}$

- Measurement is made w/100 mm chamber:
- $CTDI_{100} = \mathbf{(1/NT) \int_{-5cm}^{5cm} D(z)\, dz}$

$$= \mathbf{(f*C*E*L)/(NT)}$$

f = conversion factor from exposure to dose in air, use 0.87 rad/R

C = calibration factor for electrometer (typical= 1.0, 2.0 for some)

E = measured value of exposure in R

L = active length of pencil ion chamber (typical= 100 mm)

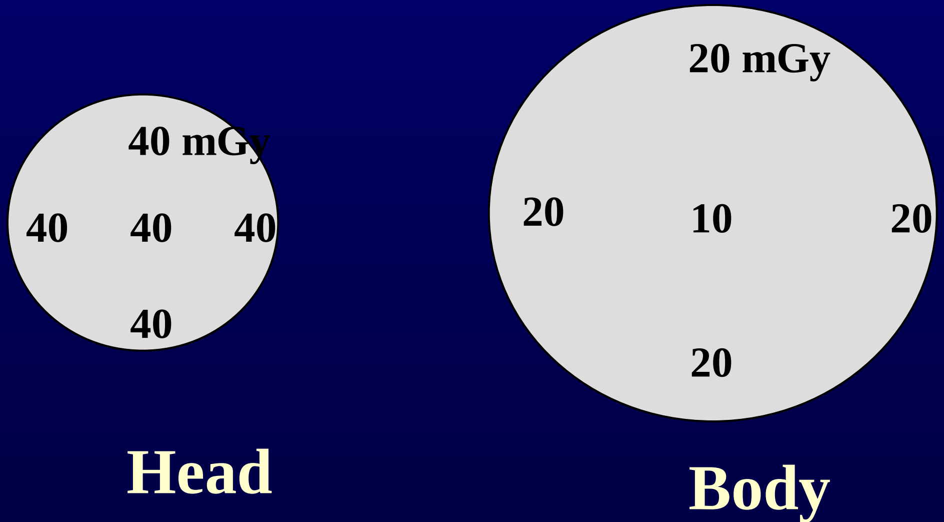
N = *actual* number of data channels used during scan

T = nominal width of one channel

$CTDI_{100}$

- $CTDI_{100}$ Measurements are done:
  - In Both Head and Body Phantoms
  - Using ONLY AXIAL scan techniques

    (CTDI = Area under the single scan dose profile)
  - At isocenter and at least one peripheral position in each phantom



$CTDI_w$

- $CTDI_w$ is a **weighted average** of center and peripheral $CTDI_{100}$ to arrive at a single descriptor
- **$CTDI_w = (1/3)CTDI_{100,center} + (2/3)CTDI_{100,peripheral}$**

CTDI $_{vol}$

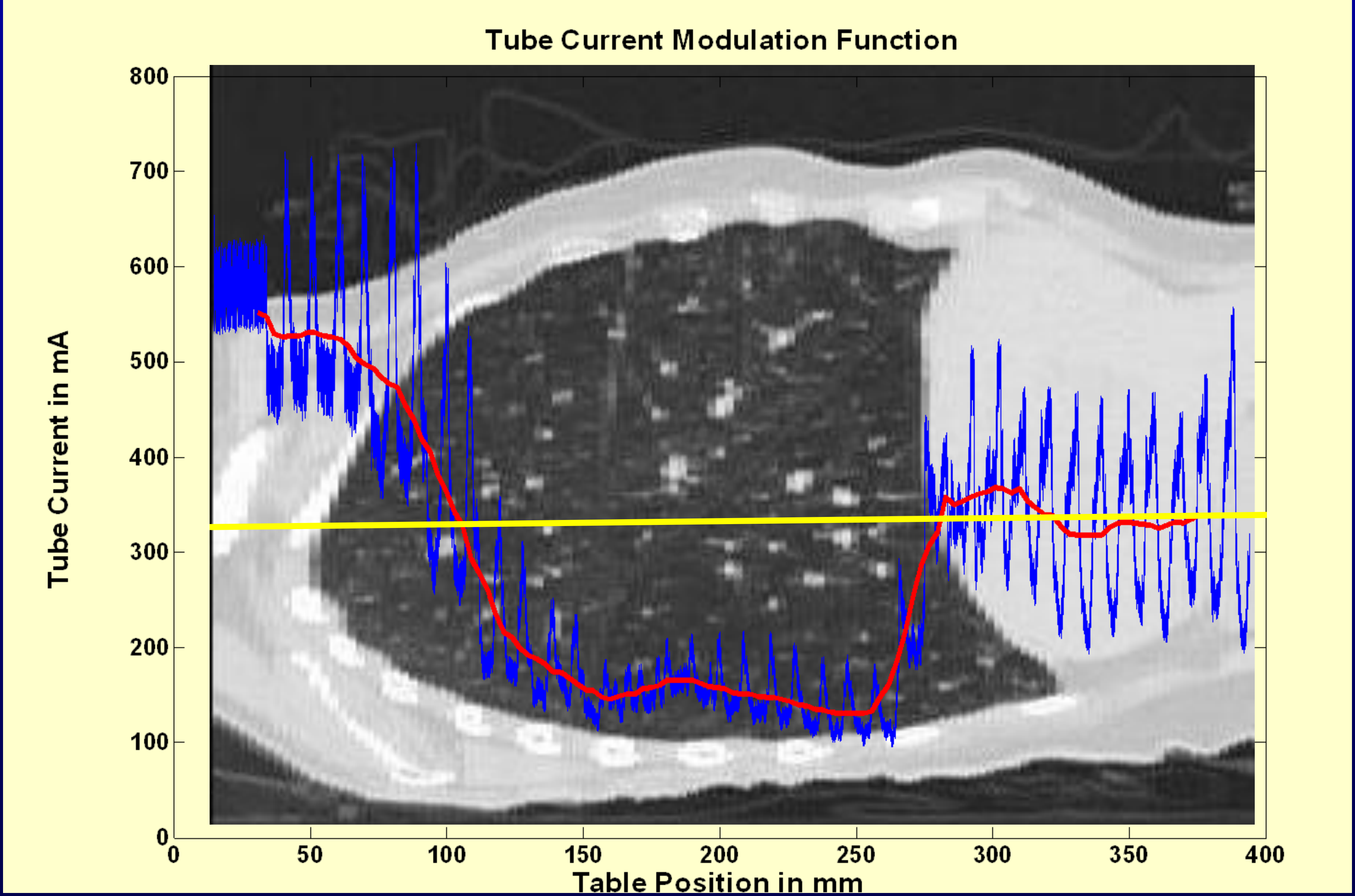
- Calculated, not measured directly
- Based on $CTDI_w$
- Measured from a single axial acquisition but calculated with a pitch value.
  - Think of this as the pitch that you *would have used* if you were performing a helical scan.
- (NOTE: CTDI not defined for helical acquisition)

CTDI $_{vol}$

- **$CTDI_{vol} = CTDI_w / Pitch$**

CTDIvol in Context of AEC

- When Tube current modulation is used:
  - CTDIvol reported is based on the average mA used throughout the scan
  - Essentially the CTDIvol at that kVp, bowtie, collimation, rotation time and then using the average mA (CTDI is very linear with mAs)


Tube Current Modulation Function
Tube Current in mA
800
700
600
500
400
300
200
100
0
0
50
100
150
200
250
300
350
400
Table Position in mm

DLP – defined

- Dose Length Product is:
  - $CTDI_{vol}$* length of scan (in mGy*cm)
- Found in most "Dose Reports"
- Includes any overscan (extra scanning for helical scans)

Effective Dose

- Most CT scans are partial irradiations of body
- How to compare the effects of different exposures to radiosensitive organs?
- Effective Dose takes into account
  - Absorbed Dose to specific organs
  - Radiosensitivity of each organ
- NOTE: Eff. Dose is NOT intended for dose to an individual; intended for populations

Effective Dose

- $E = \Sigma_T(w_T * w_R * D_{T,R})$
- w_T= tissue weighting factor (next page)
- w_R= radiation weighting coefficient (1 for photons)
- $D_{T,R}$= average absorbed dose to tissue T
- Units are: SI - Sieverts (Sv); English -rem
- 1 rem = 10 mSv; 1 Sv = 100 rem

Effective Dose

Tissue	ICRP 60 Tissue weights (w_T)	ICRP 103 weights
Gonads	0.20	0.08
Red Bone Marrow	0.12	0.12
Colon	0.12	0.12
Lung	0.12	0.12
Stomach	0.12	0.12
Bladder	0.05	0.04
Breast	0.05	0.12
Liver	0.05	0.04
Esophagus	0.05	0.04
Thyroid	0.05	0.04
Skin	0.01	0.01
Bone Surface	0.01	0.01
Brain	(part of remainder)	0.01
Salivary Glands	(part of remainder)	0.01
Remainder	0.05	0.12

Estimating Effective Dose

- To estimate effective dose accurately, you would need to ESTIMATE DOSE TO EACH RADIOSENSITIVE ORGAN !!!

$$(E = \Sigma_T (w_T * D_{T,R})) ; \qquad w_R = 1$$

- Difficult to do accurately

Estimating Effective Dose

- Computer Software
  - Based on Monte Carlo simulations
  - ImPACT calculator
  - Impactdose calculator
- K Factors (Jessen) based on DLP
  - E = DLP * k (k in mSv/(mGy*cm))
  - k= .0023 for head exams , k =0.015 for abdomen
  - See AAPM report 96 for all k factors

What is a typical reference?

- 3 mSv per year background radiation
  - Natural sources such as radon and cosmic rays
- Mettler et al now estimate 3 mSv per year from medical procedures as well
- 6 mSv **total** average annual exposure to US Population

ACR CT Dose Reference Values

- $CTDI_{vol}$
- Two levels:
  - Reference level and Pass/Fail level
  - If Reference Level is exceeded, then sites will be asked to consider some dose reduction
  - If Exceed Pass/Fail level, then Fail

Exam	Ref Level	Pass/Fail Level
– Adult Head	75 mGy	80 mGy
– Adult Abdomen	25 mGy	30 mGy
– Pediatric (5y/o) Abd	20 mGy	25 mGy
– Pediatric Head	45 mGy	

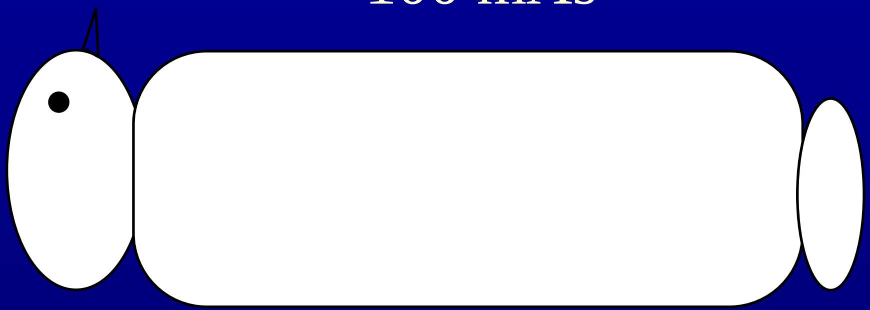
$CTDI_{vol}$ and DLP

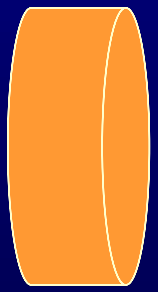
- $CTDI_{vol}$ reported on the scanner
  - (though not required in US)
- Is Dose to one of two phantoms
  - (16 or 32 cm diameter)
- Is NOT dose to a specific patient
- Does not tell you whether scan was done “correctly” or “Alara” without other information (such as body region or patient size)
- MAY be used as an index to patient dose with some additional information (later)
- See McCollough et al “CT Dose Index and Patient Dose :They Are Not the Same Thing. Radiology 2011; 259:311–316

*Scenario 1: **No adjustment** for patient size*

100 mAs

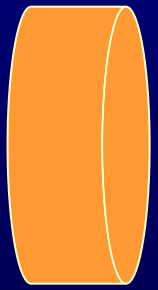
100 mAs





32 cm phantom

$CTDI_{vol}$ = 20 mGy



32 cm phantom

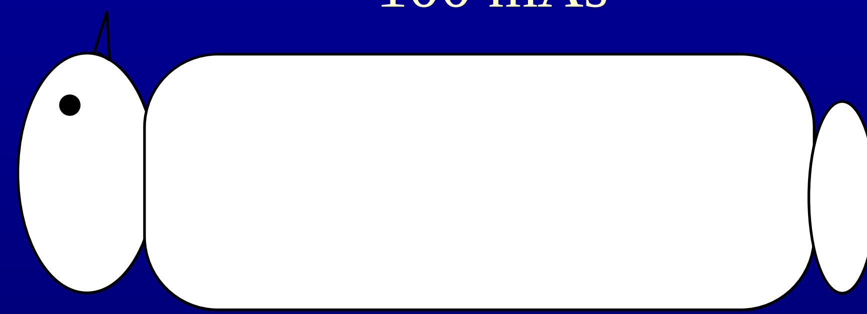
$CTDI_{vol}$ = 20 mGy

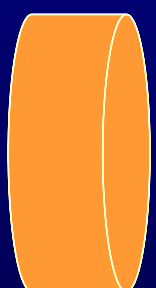
The $CTDI_{vol}$ (dose to phantom) for these two would be the same

*Scenario 2: **Adjustment** for patient size*

50 mAs

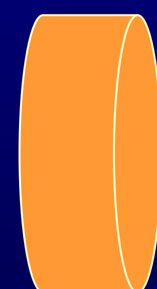
100 mAs





32 cm phantom

CTDI_{vol} = 10 mGy



32 cm phantom

CTDI_{vol} = 20 mGy

The CTDI_{vol} (dose to phantom) indicates larger patient received 2X dose

Did Patient Dose Really Increase ?

For same tech. factors, smaller patient absorbs more dose

- Scenario 1:
  - CTDI is same but smaller patient’s dose is higher
- Scenario 2:
  - CTDI is smaller for smaller patient, but patient dose is closer to equal for both

$CTDI_{vol}$

- Not patient Dose
- By itself can be misleading

- $CTDI_{vol}$ should be recorded with:
  - Description of phantom size (clarify 16 or 32 cm diameter)
  - Description of patient size (lat. Width, perimeter, height/weight, BMI)
  - Description of anatomic region

How to Calculate mSv?

- One approach (actually an approximation):

  E= DLP * k

  Where

  E = Effective Dose in mSv

  DLP = Dose Length Product in mGy*cm

  k = conversion coefficient in mSv/mGy*cm
- Formula is based on a curve fit for several scanners (circa 1990) between E and DLP
- k values are based on ICRP 60 organ weights

DLP Approach to Calculate mSv

- DLP approach
  - DLP comes from scanner
    - CTDIvol x length of scan
  - k's are known
    - (e.g. .0021 for adult head, .015 for abdomen, etc.)
    - Different k factors for peds
- Can be calculated for each patient….right?

DLP Approach to Calculate mSv

- Any assumptions here?
  - Standard Sized Patient for adults
    - 20-30 year old MALE, 70 kg, 5'7" tall
    - Is that who you just scanned?
  - Based on scanner reported CTDIvol
    - Dose to homogenous acrylic cylinder
    - (NOTE: for pediatric, some scanners currently report dose to 16 cm , others to 32 cm phantom)

DLP Approach to Calculate mSv

- A few examples

Patient Protocol Page from Siemens S16

[redacted]

UCLA

M, 3Y

Sensation 16
CT 2006G

16-Oct-2009 13:44

Ward:
Physician:
Operator:

Total mAs 3048   Total DLP 122

	Scan	KV	mAs / ref.	CTDIvol	DLP	TI	cSL
Patient Position F-SP							
Chest/ab Topo	1	80				5.3	1.0
Chest	2	80	77 / 55	1.71	39	0.5	1.5
PreMonitoring	3	80	25	1.47	1	0.5	1.5
I.V. Bolus							
Monitoring	4	80	25	4.40	4	0.5	1.5
Arterial	7	80	78 / 55	1.73	38	0.5	1.5
Venous	8	80	73 / 55	1.90	40	0.5	0.8

BTW- Which Phantom Was Used for CTDI

- Not clear in this report
- Subsequent Software Upgrades, report clearly indicates 16 or 32 cm phantom

Which Phantom Was Used for CTDI

- Currently:
- ALL HEADS (Adult/Peds) – 16 cm phantom
- ALL ADULT BODY – 32 cm phantom
- **PEDS BODY (CAUTION!!!!):**
  - Siemens, Philips: report based on 32 cm phantom
  - Toshiba: report based on 16 cm phantom
  - GE**: report 16cm OR 32 cm (depends on SFOV)
  - $CTDI_{vol}$s differ by a factor of approx 2.5
- So, previous example, $CTDI_{vol,32}$ = 1.71 mGy
- If report used 16 cm phantom, $CTDI_{vol,16}$ ~ 4.1 mGy
- PLEASE BE AWARE (this affects DLP, too)

So, what should be reported?

[redacted]

UCLA

M, 3Y

Sensation 16
CT 2006G

16-Oct-2009 13:44

Individual CTDI and DLPs
Total DLP?
Total CTDIvol?

Ward:
Physician:
Operator:

Total mAs 3048 Total DLP 122

	Scan	KV	mAs / ref.	CTDIvol	DLP	TI	cSL
Patient Position F-SP							
Chest/ab Topo	1	80				5.3	1.0
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Depends….What Do You Need/Want to Do?

- Meet State/Local Regulations?
- Record/Report Dose because it is the "right thing to do"?
  - Record CTDIvol
  - Record "Patient Dose"
  - (Remember, they are NOT the same thing)

Ca SB 1237 – Important Clauses

- 115111. (a) Commencing July 1, 2012…..
- (b) The facility conducting the study shall electronically send each CT study and protocol page that lists the technical factors and dose of radiation to the electronic picture archiving and communications system.
  - Patient Protocol page or DICOM RDSR fulfills this requirement
- (d) Subject to subdivision (e), the radiology report of a CT study shall include the dose of radiation by either recording the dose within the patient's radiology report or attaching the protocol page that includes the dose of radiation to the radiology report.
  - Not all scanners are capable of CT RDSR
  - Would be nice to electronically integrate with radiology report
- (f) For the purposes of this section, dose of radiation shall be defined as one of the following:
- (1) The computed tomography index volume (CTDI vol) and dose length product (DLP), as defined by the International Electrotechnical Commission (IEC) and recognized by the federal Food and Drug Administration (FDA). (2) The dose unit as recommended by the American Association of Physicists in Medicine.

To Comply With State Law

- We only need to report CTDI and DLPs
- But which ones?
  - Individual CTDI/DLPs?
  - Totals?
  - Both?

When Does It Make Sense to Add $CTDI_{vol}$s

- When same anatomic region is scanned repeatedly and assumptions of CTDI apply (table movement, large anatomic region such as head, chest, abdomen, etc.)
- Examples:
  - Non-con chest followed by post-contrast chest

When Does It NOT Make Sense to Add $CTDI_{vol}$s

- Different anatomic regions
- No table motion (perfusion scan)
- Examples:
  - chest followed by abdomen/pelvis

When Does It Make Sense to Add DLPs

- Similar to CTDIvol's
- When same anatomic region is scanned repeatedly and assumptions of CTDI apply (table movement, large anatomic region such as head, chest, abdomen, etc.)
- Examples:
  - Non-con chest followed by post-contrast chest

When Does It NOT Make Sense to Add DLPs

- Again, Similar to CTDIvol's
- Different anatomic regions
- No table motion (perfusion scan)
- Examples:
  - Head followed by C/A/P
  - Even Chest followed by abdomen/pelvis

Limitations to CTDI

- Is CTDIvol Organ Dose?

AAPM TG 204

AAPM Report No. 204

Size-Specific Dose Estimates (SSDE) in Pediatric and Adult Body CT Examinations

Report of AAPM Task Group 204, developed in collaboration with the International Commission on Radiation Units and Measurements (ICRU) and the Image Gently campaign of the Alliance for Radiation Safety in Pediatric Imaging

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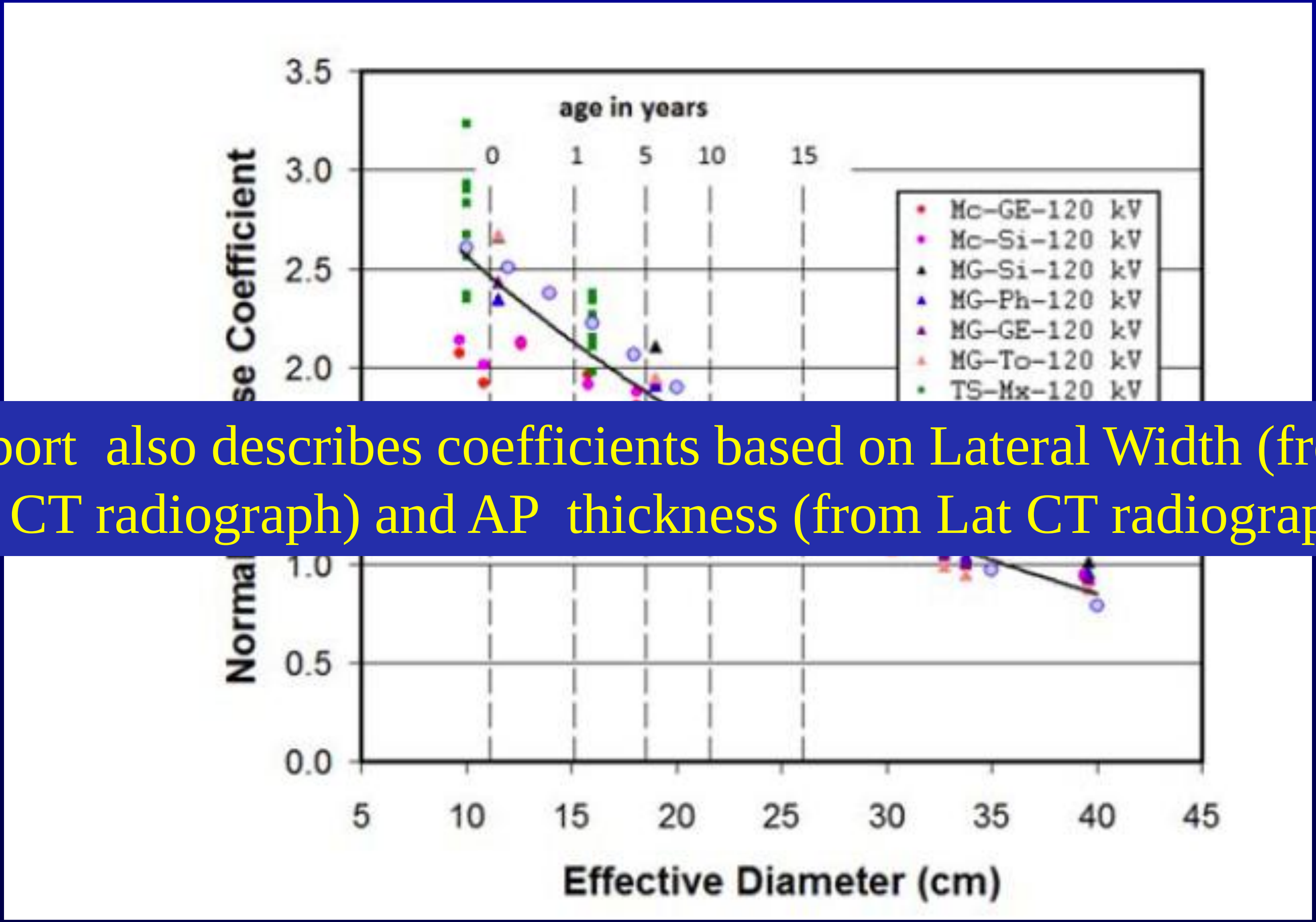
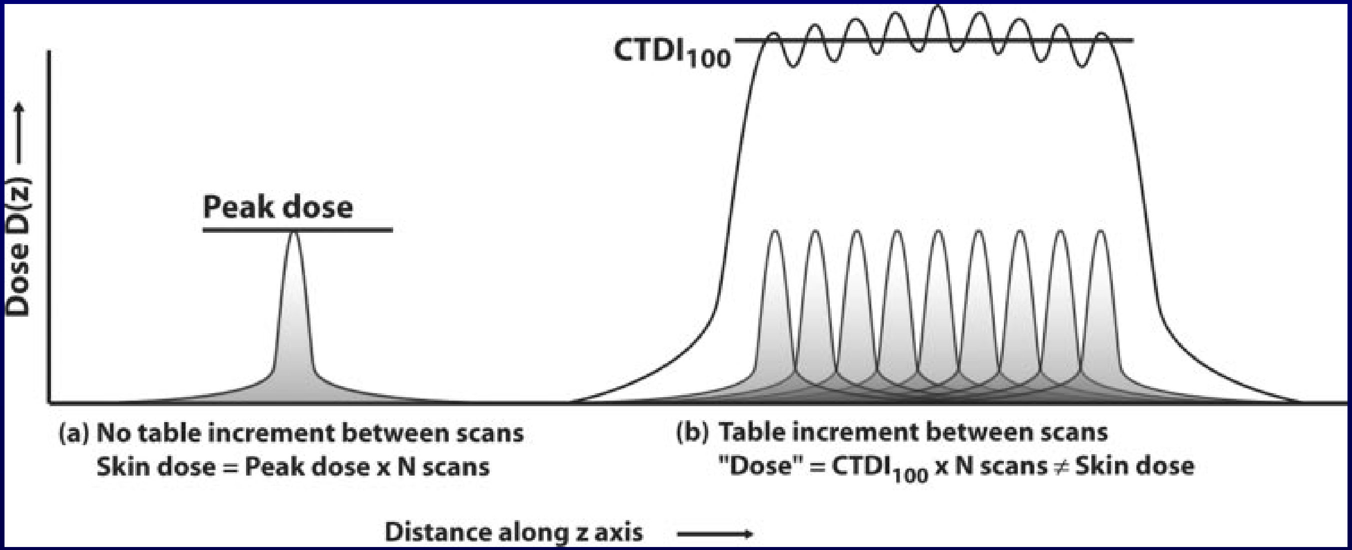
AAPM TG 204



Report also describes coefficients based on Lateral Width (from PA CT radiograph) and AP thickness (from Lat CT radiograph)

Does $CTDI_{vol}$ Indicate Peak Dose?

- $CTDI_{vol}$ is a weighted average of measurements made at periphery and center of cylindrical phantom
- Defined to reflect dose from a series of scans performed w/table movement



Does $CTDI_{vol}$ Indicate Peak Dose?

- $CTDI_{vol}$ is a weighted average of measurements made at periphery and center of cylindrical phantom
- Defined to reflect dose from a series of scans performed w/table movement
- Is not patient dose (not even skin dose)
- Typically OVERestimates skin dose in cases where scan is performed with no table movement (e.g. perfusion scans)

- BTW, AAPM TG 111 dose metric will do a better job here (specifically defines a measure with no table motion);
  - But still not patient dose (Dose to phantom)

Reporting Dose: How To Do It Right?

- Phase 4: DICOM SR, Body Size Adjusted, Organ Doses; Auto-Insert into Radiology Report
- Phase 3: DICOM SR, Body Region and Size Adjusted, Auto-insert into Radiology Report
- Phase 2 (We WANT to be Here before July 1, 2012)
  - DICOM SR, Auto-insert into Radiology Report
- Phase 1 (We are Part of the Way Here):
  - DICOM SR, Dictated into Radiology Report
  - Some scanners create DICOM SR, not easy to read and dictate
- Phase 0 (We Are Currently Here):
  - Patient Protocol Page, Info. Dictated into Radiology Report

Roadmap for Phased Approach to Reporting Radiation Dose

Level 2: Patient Organ Doses

- DICOM SR, Size Adjusted, Organ Doses ,
- Auto-insert into Radiology Report,
- Queriable Database of Organ Doses

Level 1: Adjust CTDIs, DLPs for Patient Size

- Needs Consistent Metric of Patient Size
- Still need method to determine appropriate addition of CTDIs and/or DLPs

Level 0: Reporting CTDIs, DLPs

- Patient Protocol Page, Info. Dictated into Radiology Report
- Does NOT have adjustment for patient size
- Just Adding CTDIs and/or DLPs may be ***inappropriate***

X We are Here

Summary of CTDI

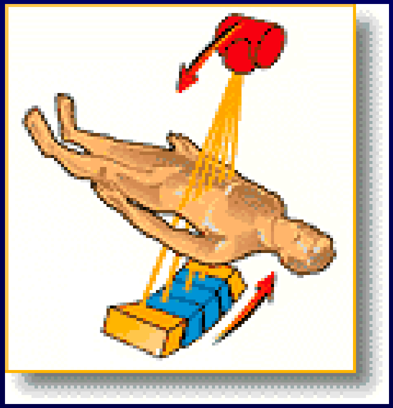
- Summary of CTDIvol
  - Is not patient dose
  - Is dose to a reference sized phantom (reference can vary from Peds to Adult or it might be same)
  - Needs to be adjusted for patient size
  - Need methods to determine when to add CTDIs and when not to (especially in automated fashion)

  - Is not skin dose (overestimates skin dose for perfusion scans)
  - TG 111 measurements (small chamber) will do a better job when that is standardized

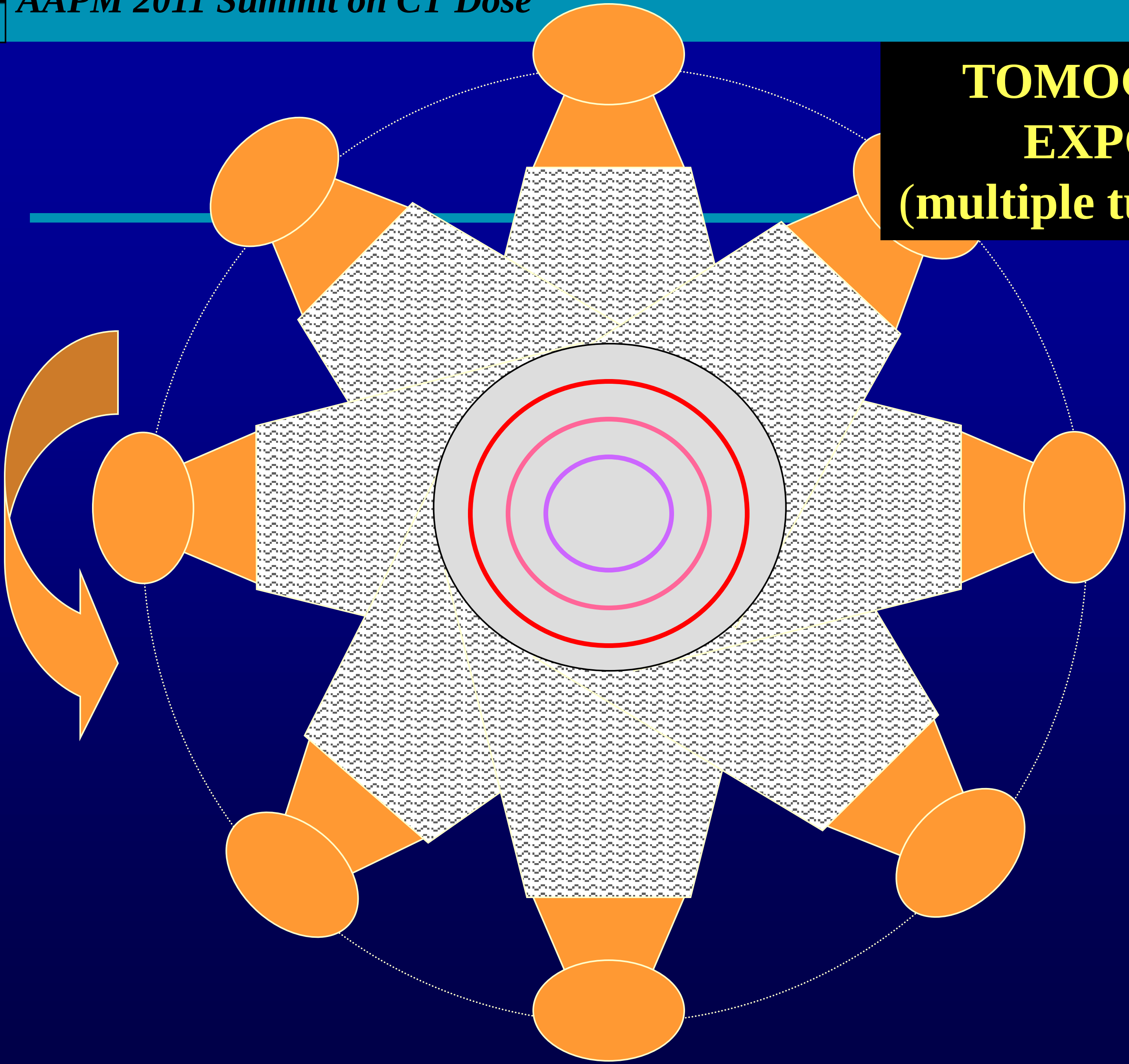
Appendix 1 – CTDI basics

CT –Specific definitions

- What is unique about CT?
  - Geometry and usage
  - Exposure is at multiple points around patient
  - Typically thin? (0.5 - 40 mm) beam widths
    - Some beam widths up to 160 mm nominal
  - Multiple Scans (Series of Scans)

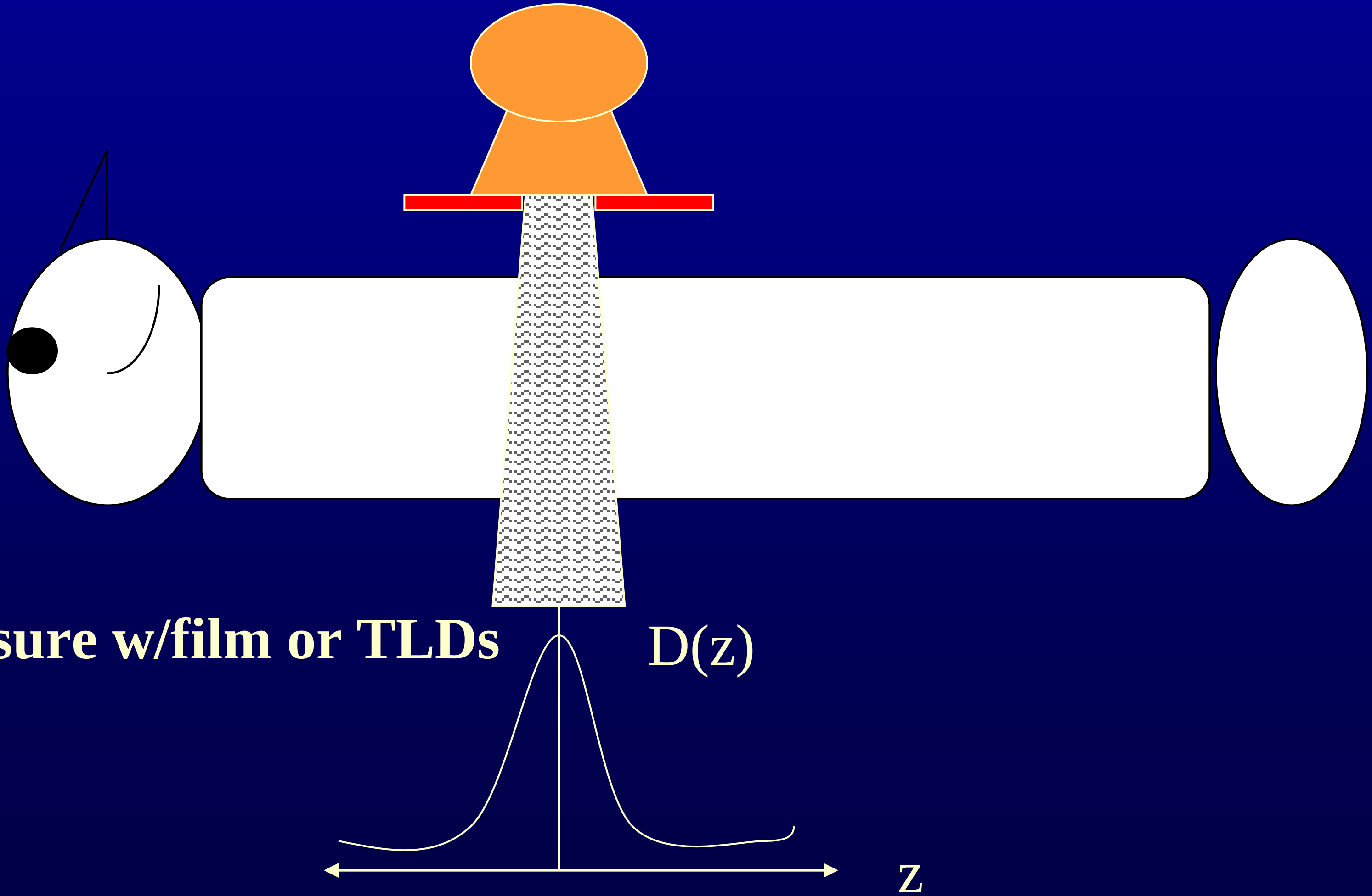


TOMOGRAPHIC EXPOSURE (multiple tube positions)



CT Dose Distributions

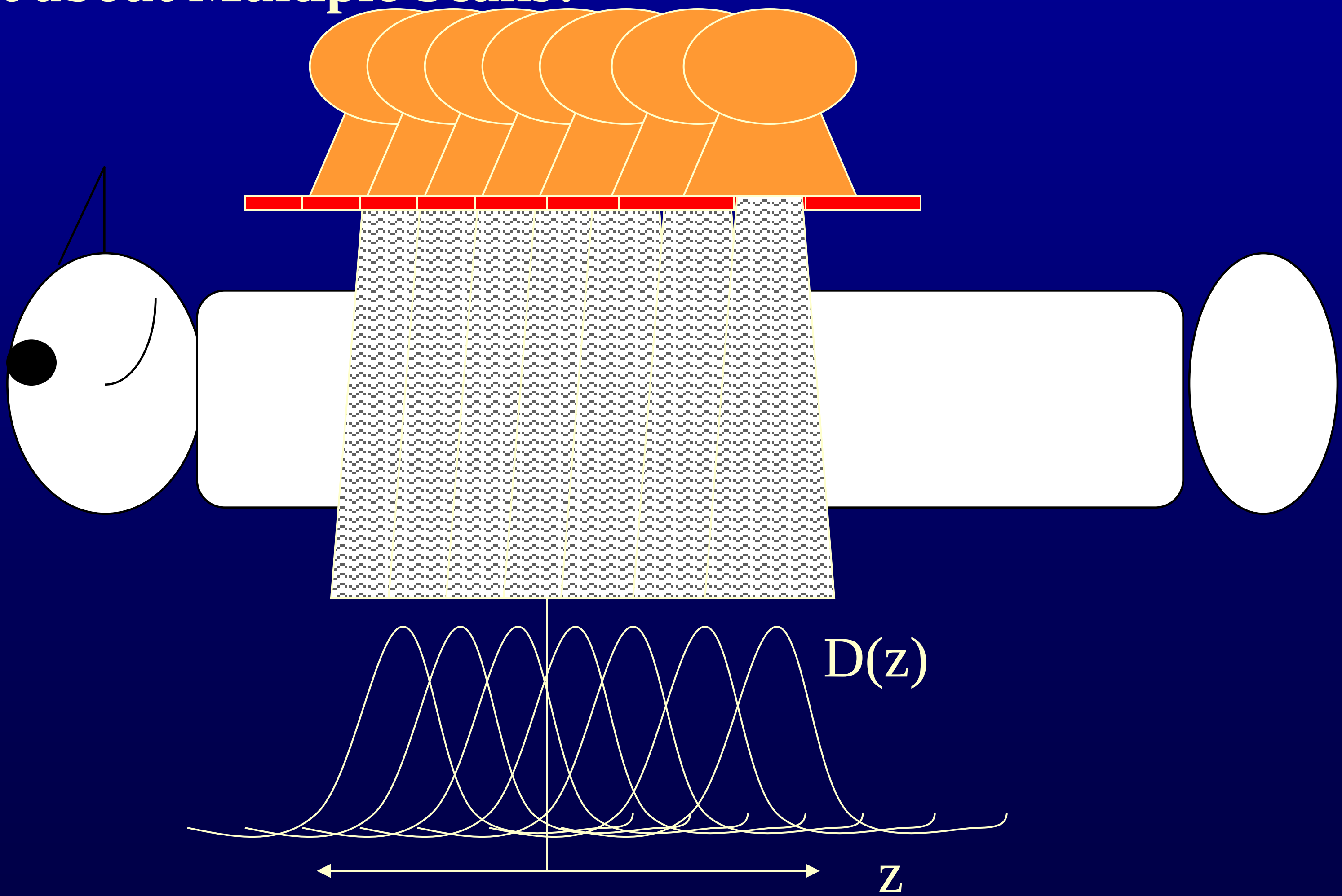
- **D(z) = dose profile along z-axis from a single acquisition**



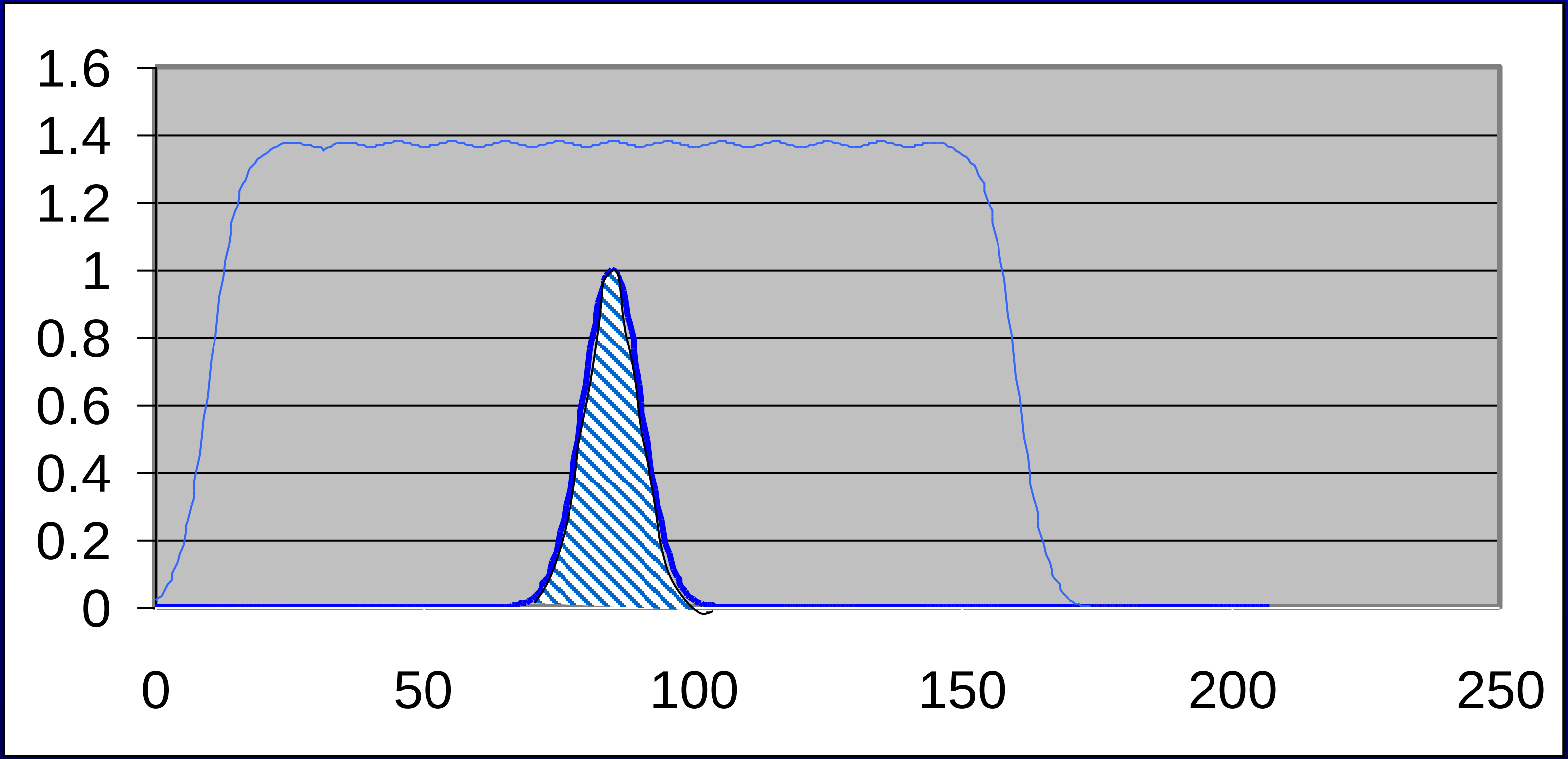
- **Measure w/film or TLDs**

CT Dose Distributions

- **What about Multiple Scans?**

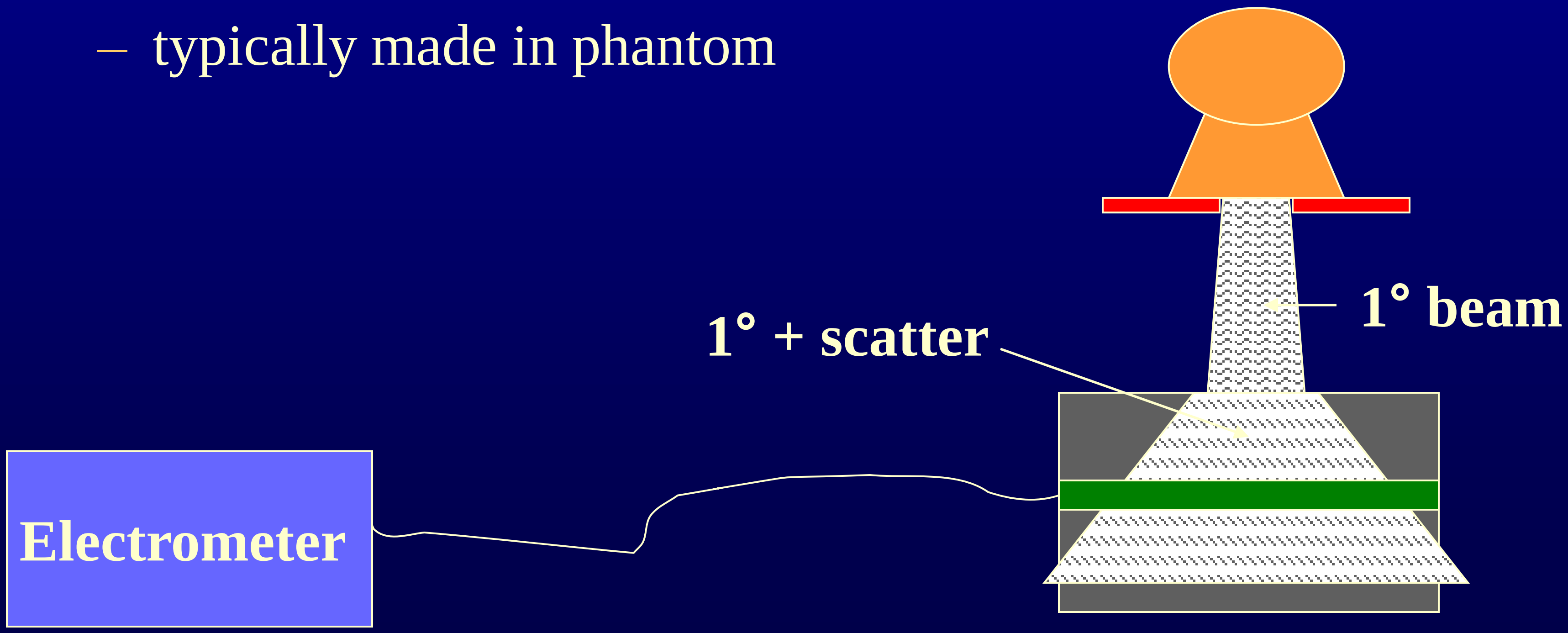


CT Dose Distributions



(CTDI) – defined

- How to get area under single scan dose profile?
  - Using a 100 mm pencil ion chamber
  - one measurement of an axial scan
  - typically made in phantom



Coming Attractions – TG 111/200

- Basic ideas
  - CTDI underestimates dose from contiguous scans (e.g. helical) by not capturing scatter tails.
    - Some scanners have beam widths larger than 100mm now, so not even all primary is captured.
  - CTDI overestimates dose from axial scan with no table motion because scatter tails included
- Replace CTDI w/ small chamber measurement
- Measure Deq w/long phantom and long scan
  - capture all scatter tails

AAPM TG 111 CT Dose (Small Chamber)

Comprehensive Methodology for the Evaluation of Radiation Dose in X-Ray Computed Tomography

A New Measurement Paradigm Based on a Unified Theory for Axial, Helical, Fan-Beam, and Cone-Beam Scanning With or Without Longitudinal Translation of the Patient Table

Report of AAPM Task Group 111:
The Future of CT Dosimetry

February 2010

Coming Attractions – TG 111/200

- Helical scan or axial scan, however scan is performed clinically
  - Perform measurement w/table motion or no motion
- Three phantom lengths or one phantom length
  - Full characterization of Deq
  - Or a reference measurement for QA
- TG 111 report on AAPM website
- TG 200 working out phantom and protocol


23/03/2011 15:37

Other Coming Attractions

Proposed IEC Standard (Amend 1, Ed. 3)

- Modify CTDI measurement, based on beam width (NT)
  - NT≤ 40 mm, conventional CTDI w/single axial scan

$$CTDI_{100}(N \times T) = \frac{1}{N \times T} \int_{-50mm}^{+50mm} D(z)dz$$

  - NT > 40 mm, first
    - conventional CTDI w/single axial scan at ref. NT (≤ 40 mm)
    - Then scale by ratio of measurements made free-in-air at desired NT and reference NT

$$CTDI_{100}(N \times T) = \frac{1}{(N_{ref} \times T_{ref})} \times \left(\int_{-50mm}^{+50mm} D_{ref}(z)dz \right) \times \left(\frac{CTDI_{free-in-air}(N \times T)}{CTDI_{free-in-air}(N_{ref} \times T_{ref})} \right)$$

Coming Attractions

- Proposed IEC Standard (Amend 1. Ed. 3) provides consistent offset from ideal (CTDIw,∞)