Measurement of Skin Dose –
Sources of Uncertainty

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Purpose

1. Present a framework to recognize and minimize error associated with peak skin dose calculation.
2. Reduce known and substantial bias error to acceptable random error.
3. Suggest a real-world estimate of precision for reporting calculated skin dose.

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Outline

1. Types of error
2. Reducing bias error to random error
3. Estimate a likely range of skin dose values

A tiered approach

- √ Single exposure event (foot pedal event)
- √ Single procedure (multiple exposure events)
- Multiple procedures
  - Incorporate tissue repair processes

- √ First order correction factors – MUST HAVE!
- √ Higher order correction factors – Even better!
- Improve precision of correction factors

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Types of error

- Bias
  - Unknown constant offset from actual value
  - Can lead to substantial error and must be corrected
  - Remedy by measured correction factor with acceptable random error

Types of error

- Random
    - Random offset from actual value
        - Instrumentation error
        - Intra and inter-observer variability
    - Unavoidable in physical systems
    - For relative uncertainties, combine by summation of the variances
    - Minimize individual error sources to minimize net uncertainty

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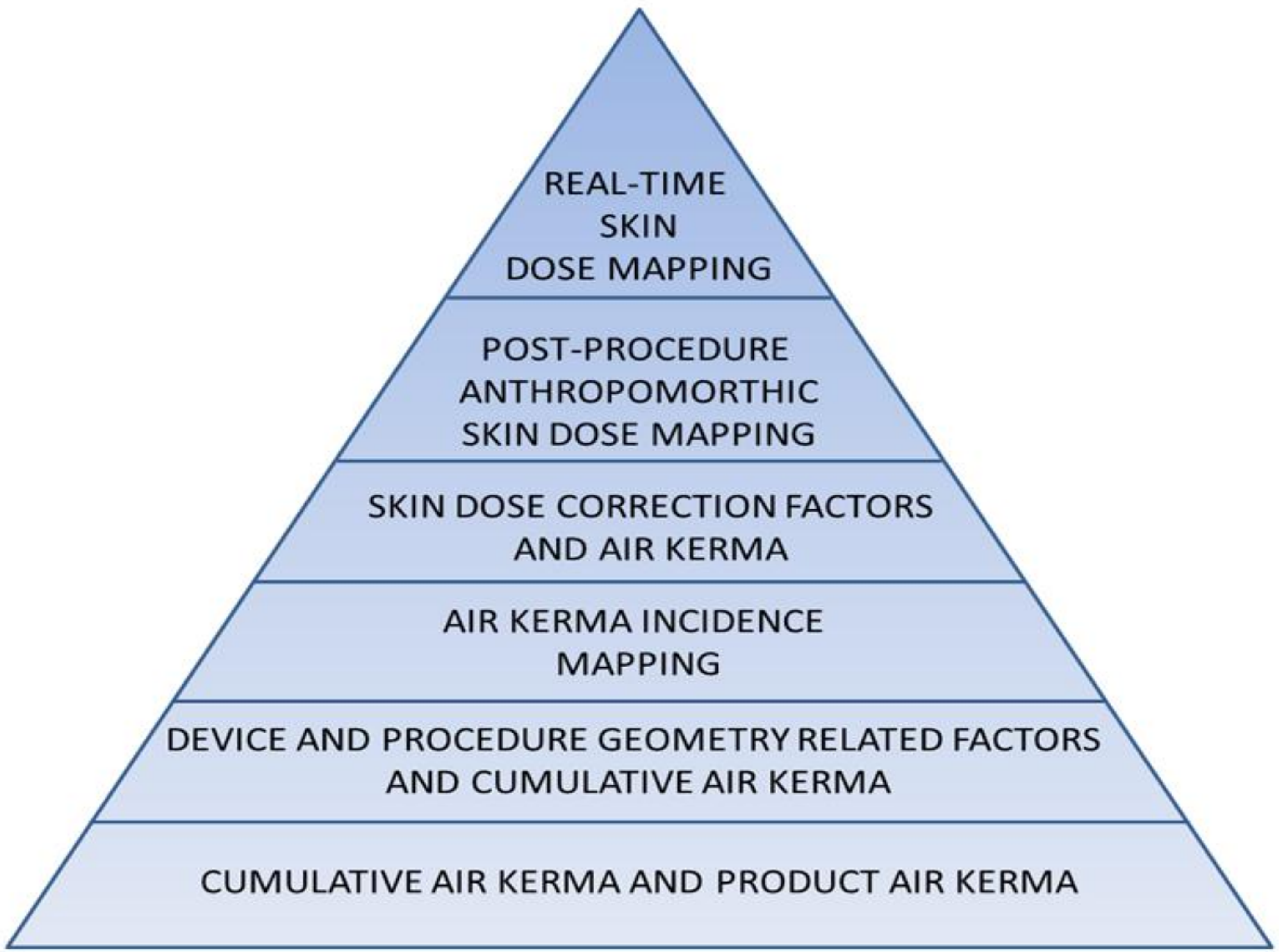
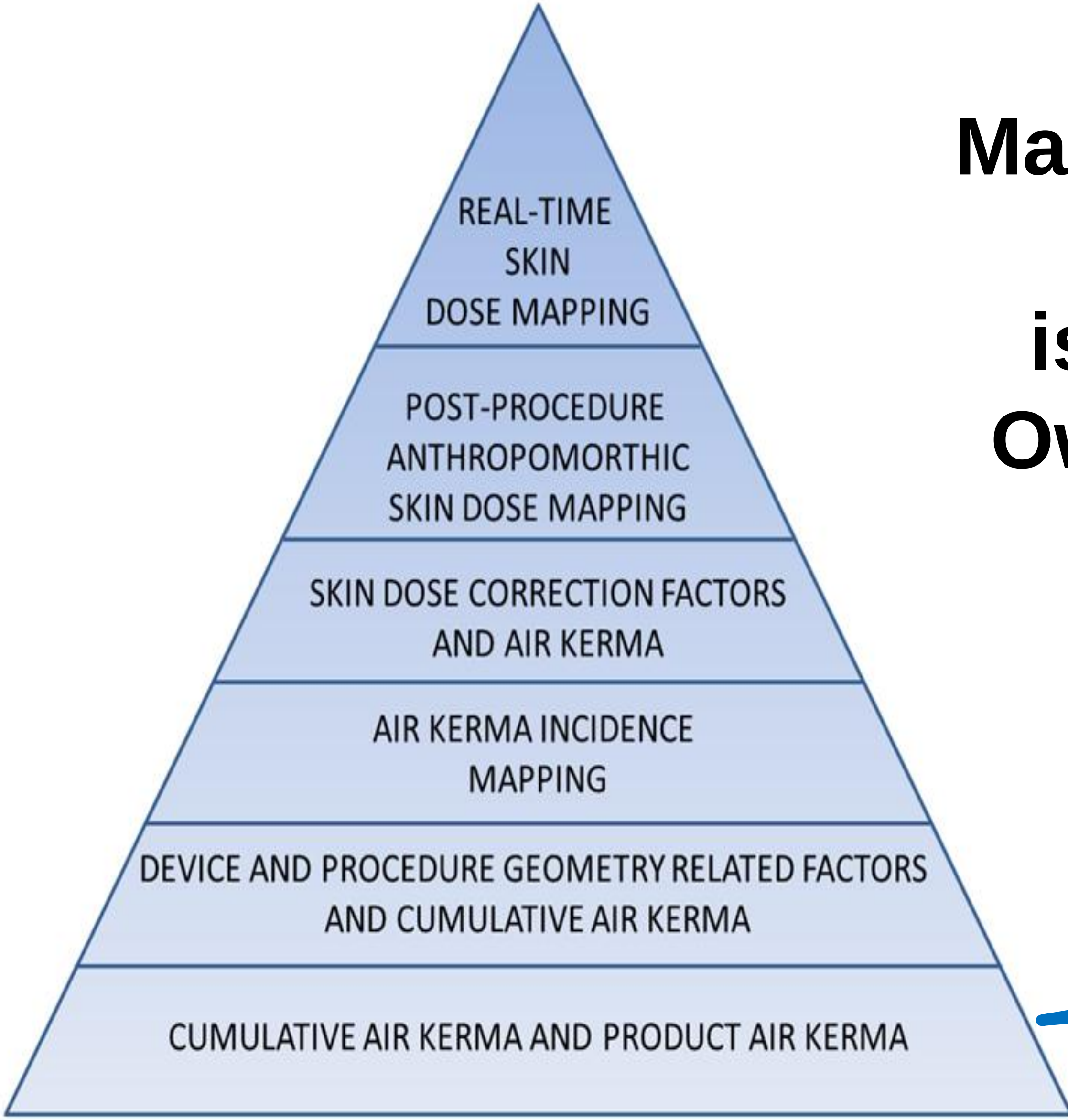
TG246 Patient Dose with Diagnostic Radiations - Fluoroscopy





Manufacturers AK tolerance is noted in the Owners Manual!

Physicist's Values

FIX: AK Calibration

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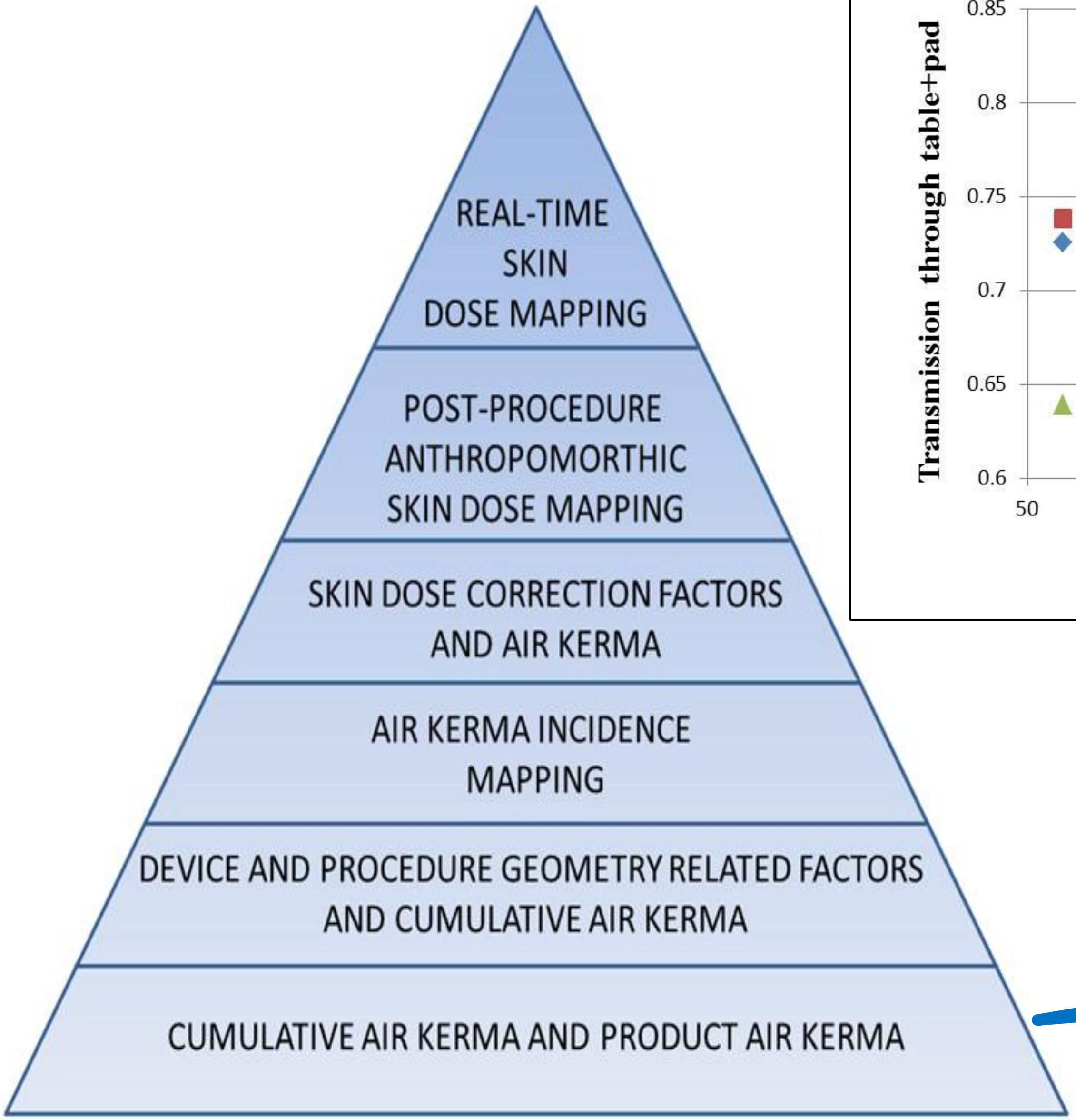
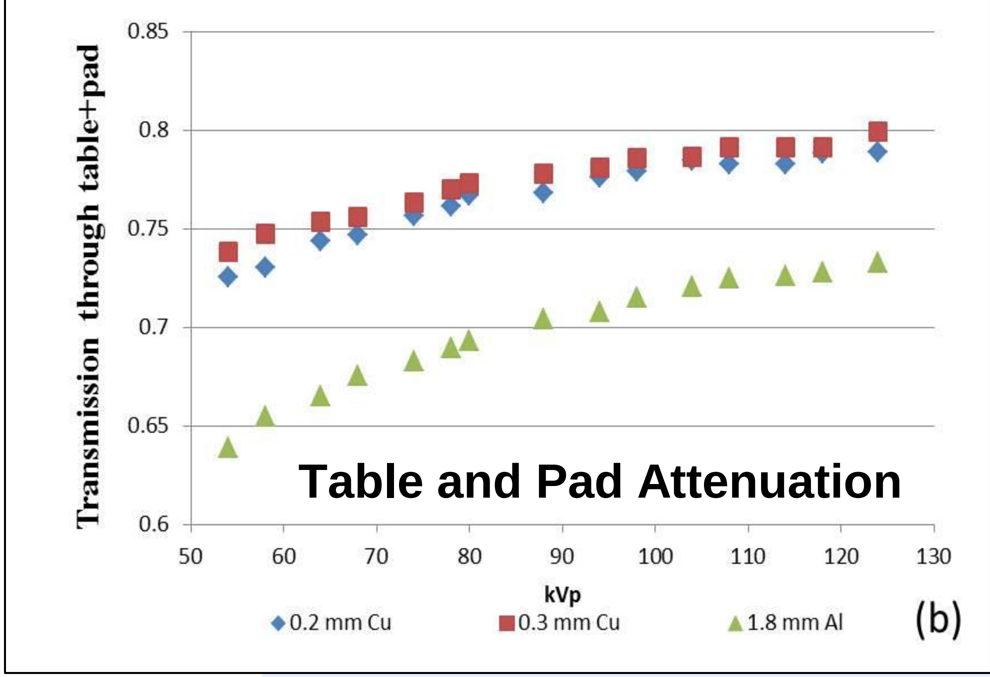


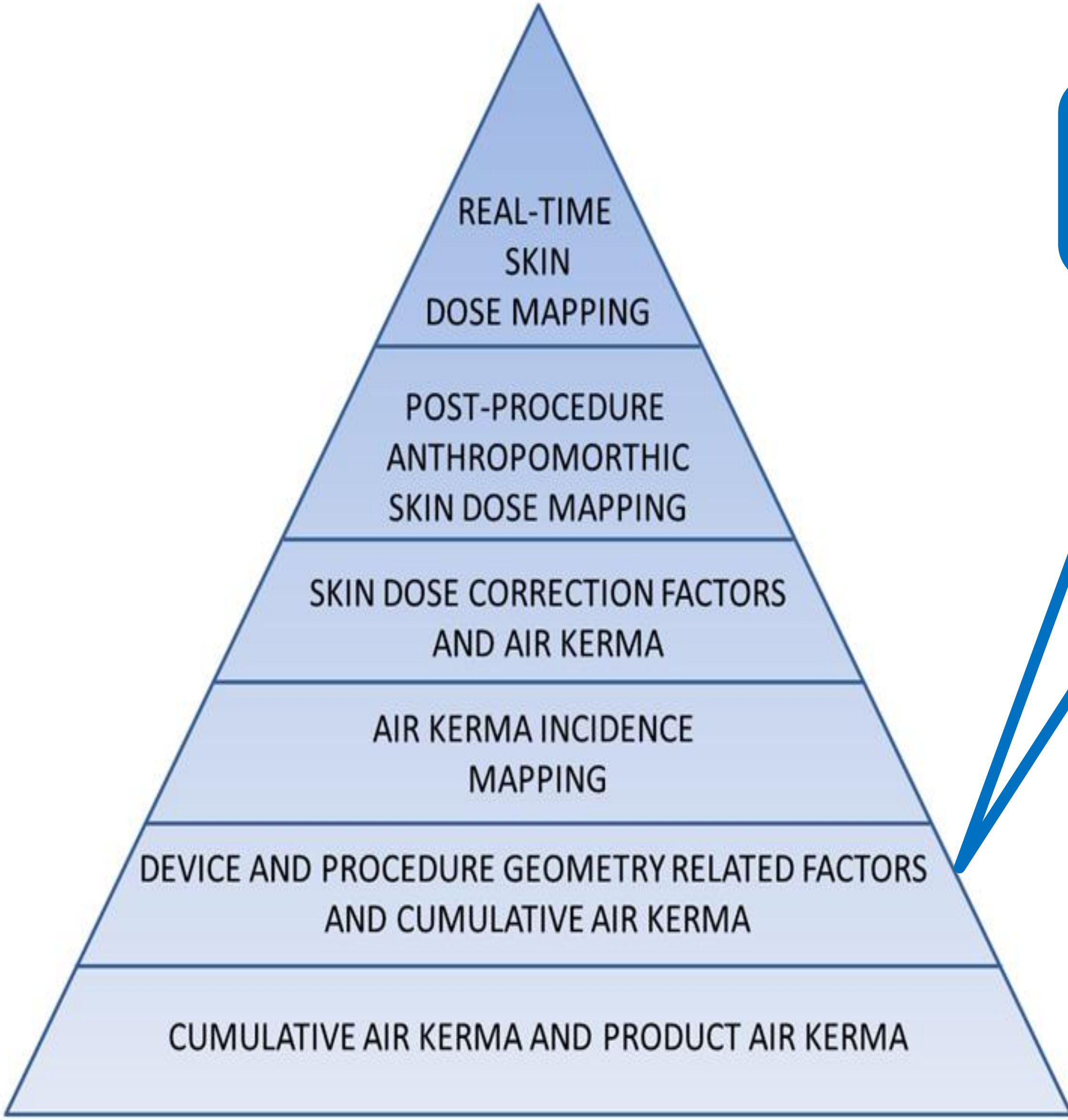


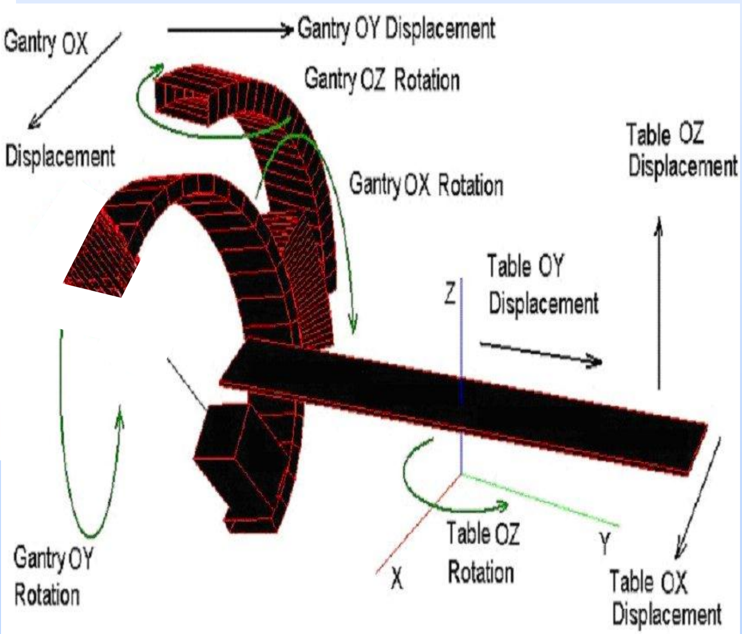
Physicist's Exposure Corrections

Table and Pad

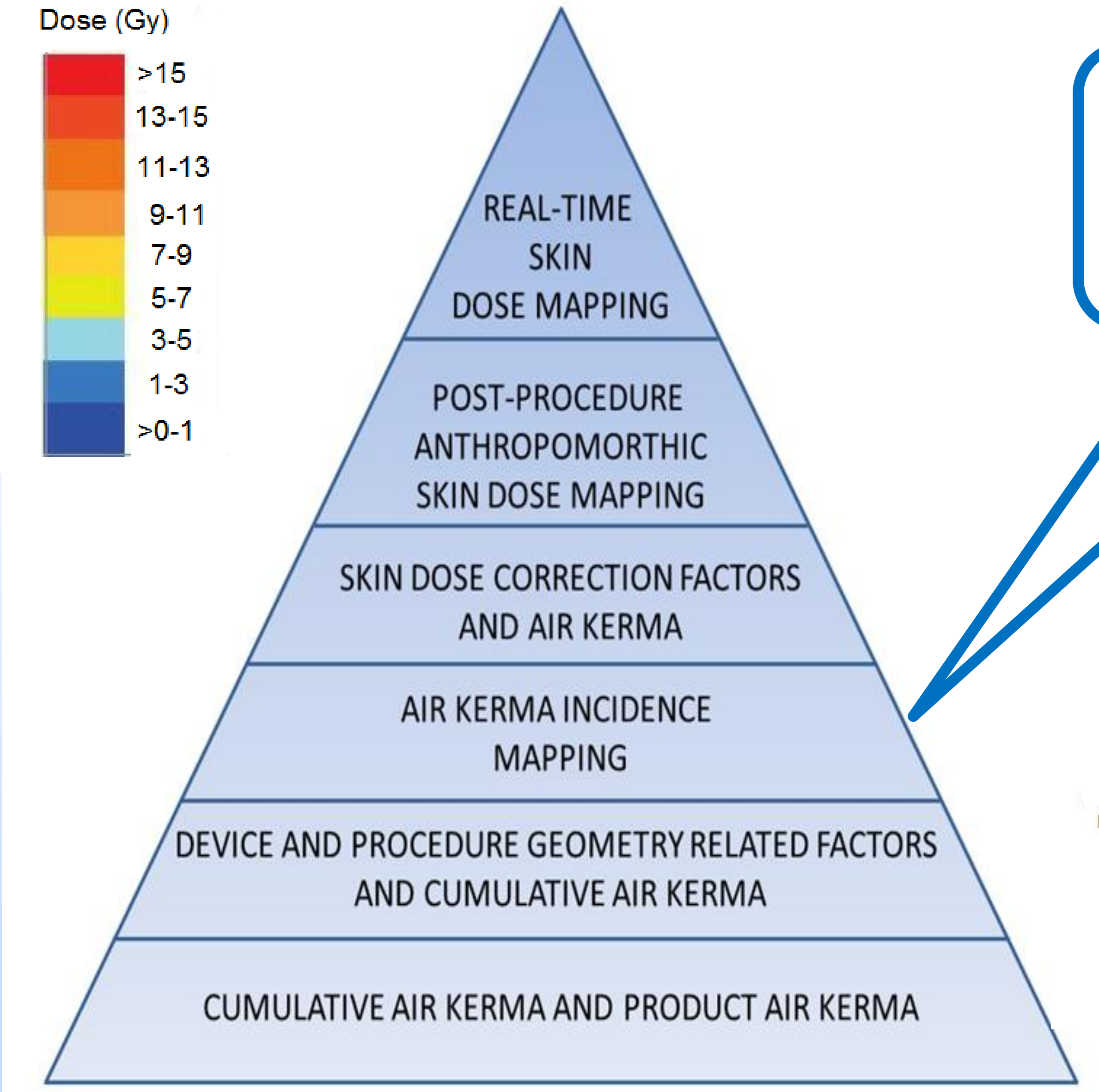
Table and Pad Attn values From Dan Bednarek

C-Arm Angulation
Table Movement

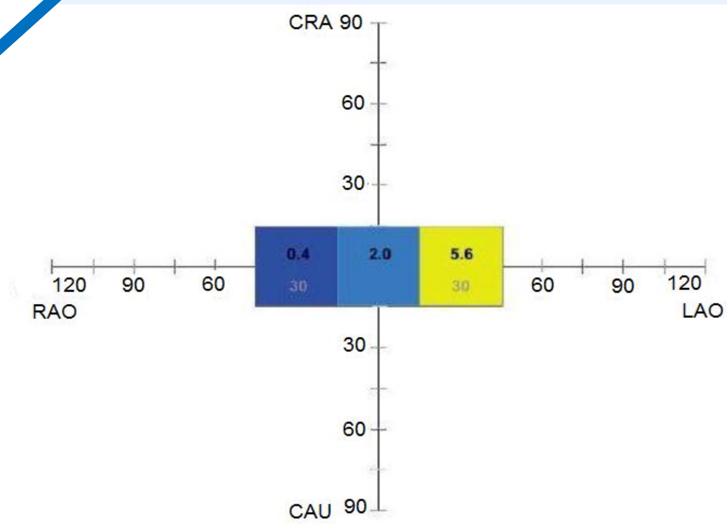




Chugh K, Dinu P, Bednarek DR, et al, Proc of SPIE 5367, 464 (2004).



Peak Skin *Exposure*
Exposure LOCATIONS
Exposure OVERLAP
At IRP



Incident AK Mapping
From Clemence Bordier

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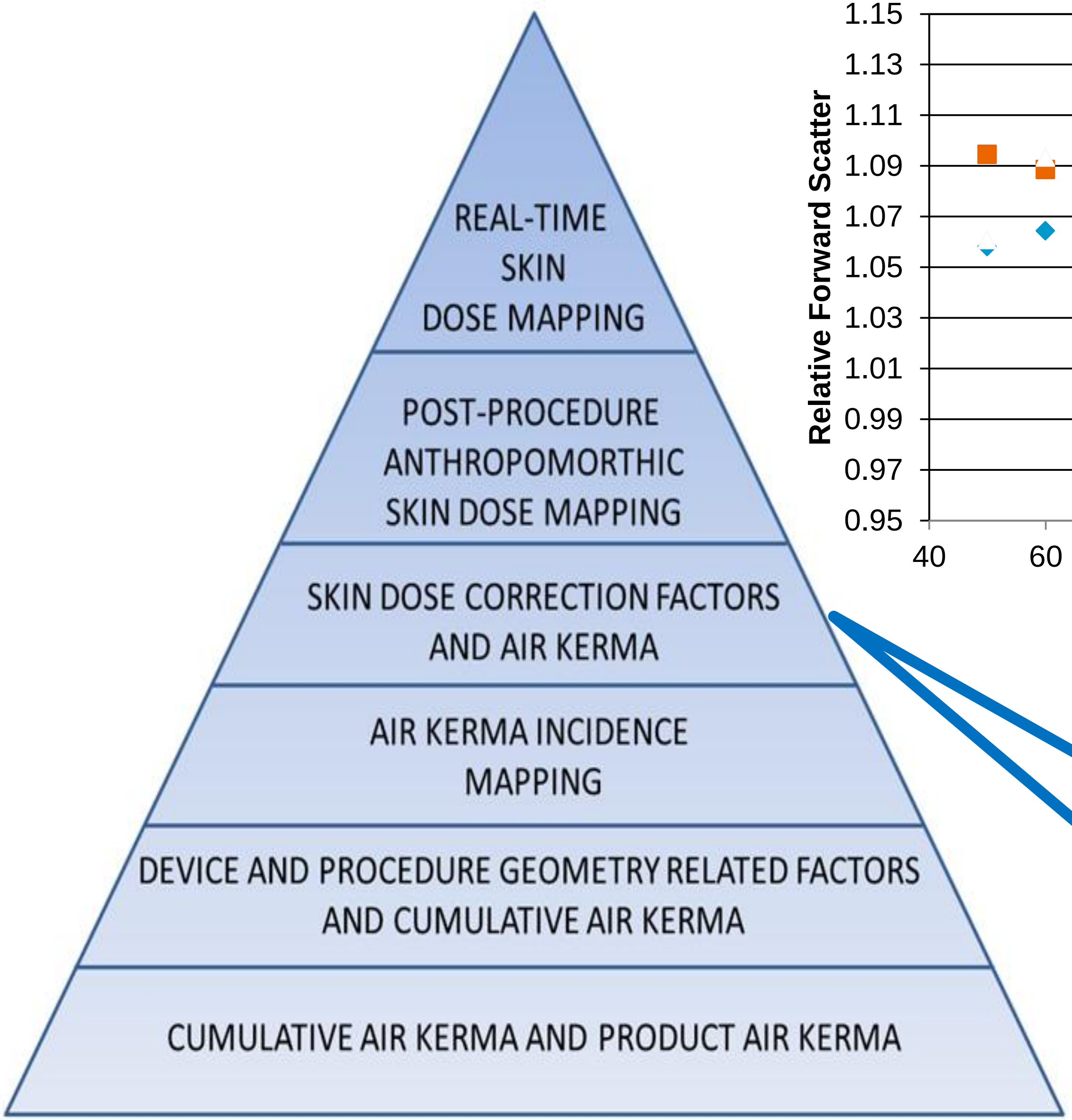

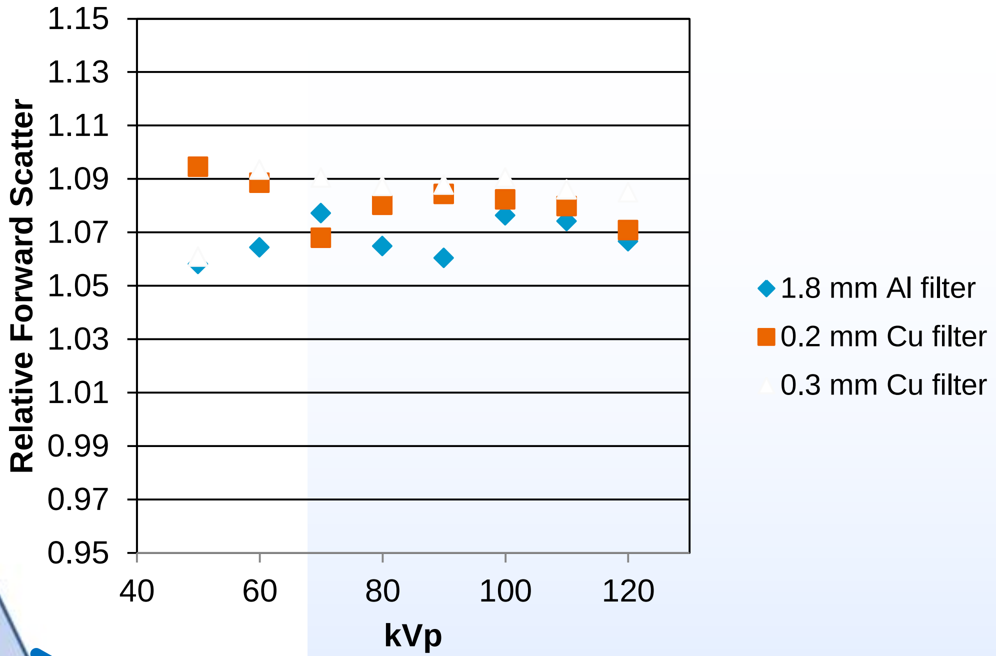

Exposure to Dose

Forward Scatter

From Table - Pad

Forward Scatter values

From Dan Bednarek

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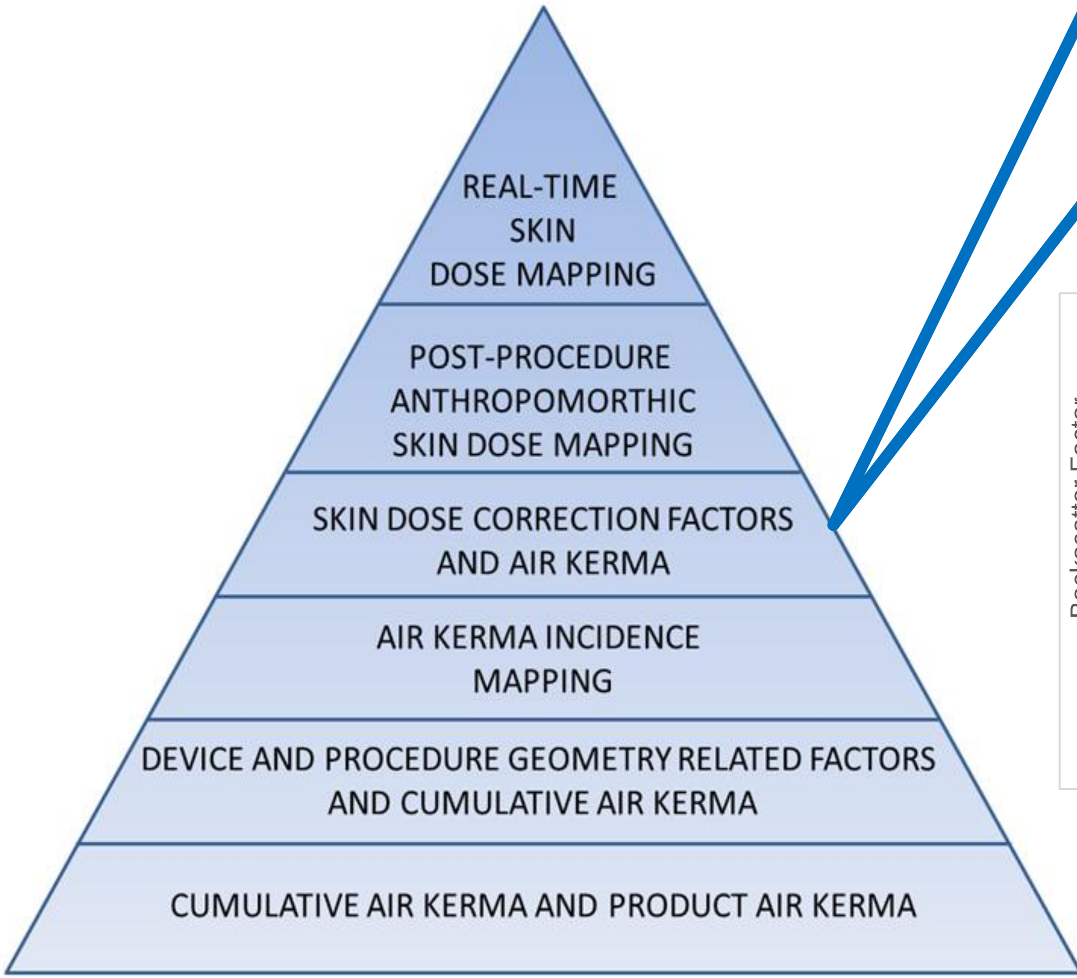
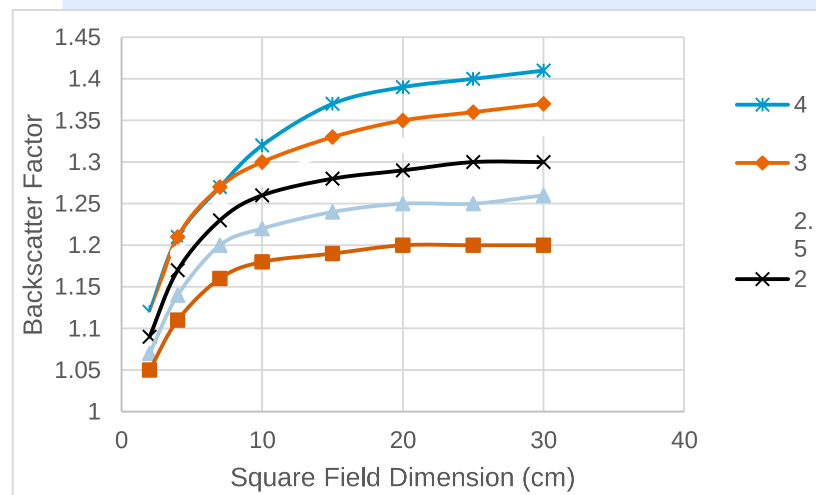
Exposure to Dose

Back Scatter



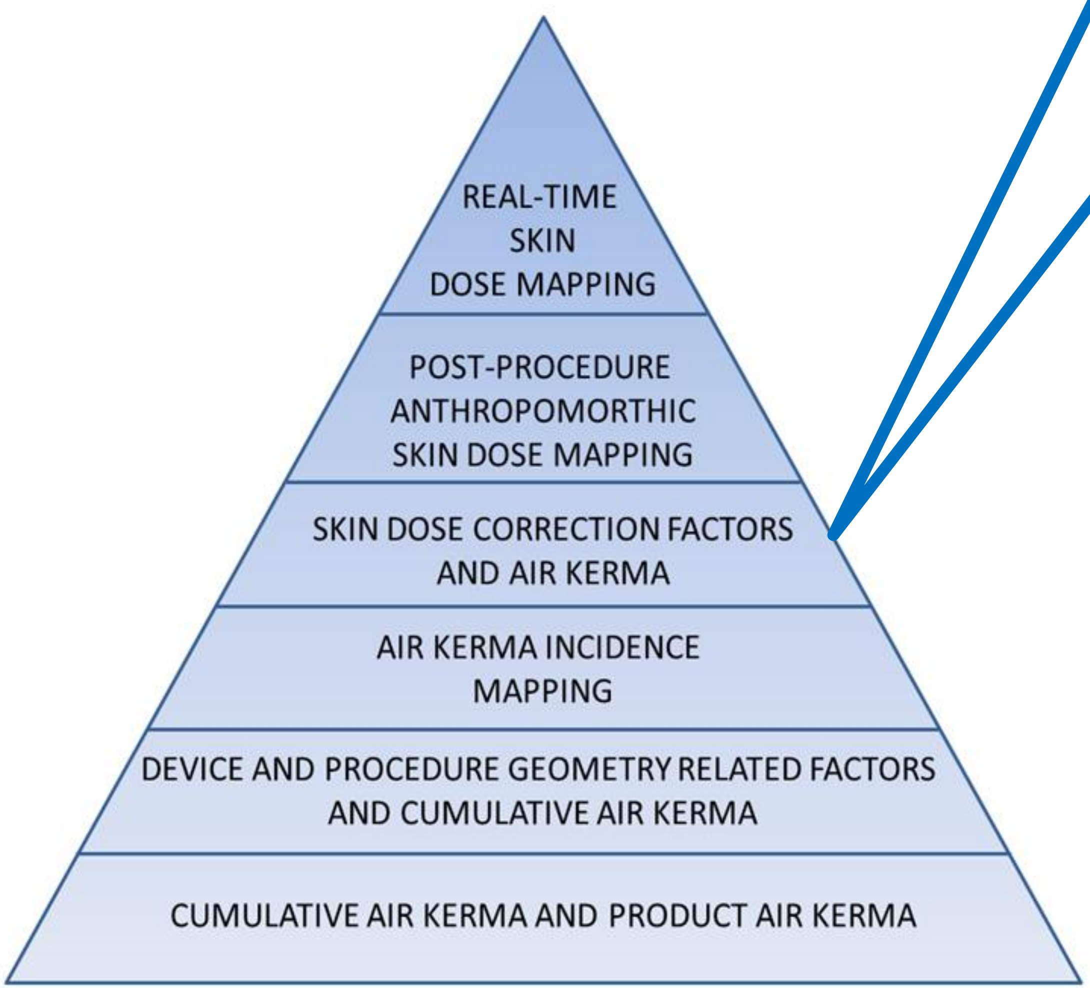


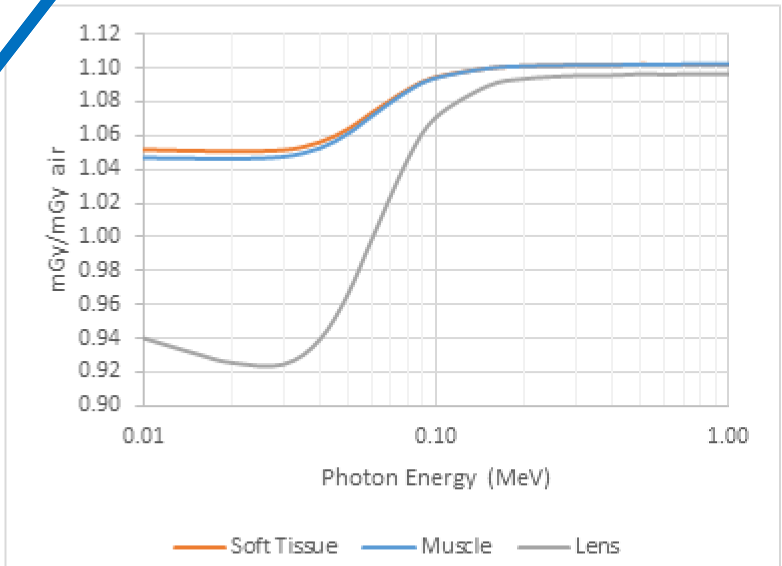
Back Scatter values

From Dan Bednarek

Exposure to Dose

f Factor





f Factor graph

From Dan Bednarek

Well known bias errors

- Air kerma (as reported by the system)
- Table and pad attenuation
  - Spectral effects
  - Angular incidence
- Table and pad forward scatter
- Tissue backscatter
- Soft-tissue f-factor
  - Homogeneity effects

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Less well known bias errors

- X-ray source to skin distance
  - Lateral x-ray tube
  - Non-target anatomy (arms)
  - Patient position on table
  - Mismatch between virtual phantom and real patient

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Even Less well known bias errors

- Overlapping fields
  - Same procedure
  - Subsequent procedure
- X-ray field shape
  - Secondary collimators
  - Area is known, width and length not in DSR
- Wedge filter
- Heel effect
- Imaging during system or patient movement

Strategy to manage bias error

- Apply correction factors for known sources of bias
- Investigate and address less known sources of bias
  - Review the images, including DICOM headers
  - Review the DICOM Dose Structured Report
  - Interview staff
- Assign realistic error estimates to correction factors
- Calculate overall error estimate
- Report a likely range of skin dose values

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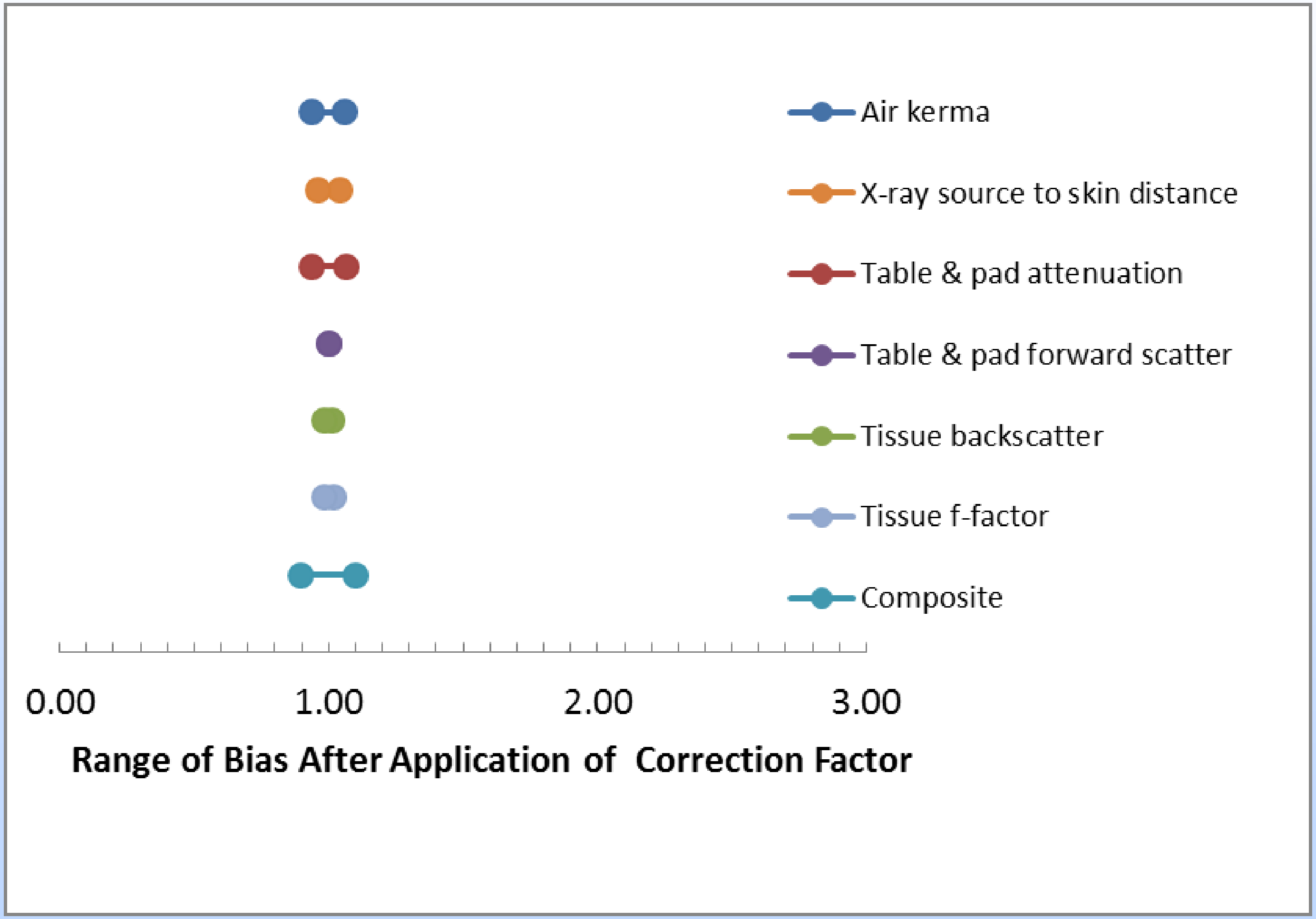
Example: Error mitigation



Modeling error as a normal distribution

- Approximation for unknown actual probability function.
- Provides a convenient mathematical foundation for combining sources of uncertainty.
- $P(\mu, \sigma, x) = \frac{1}{\sigma\sqrt{2\pi}}\, e^{-\frac{(x-\mu)^2}{2\sigma^2}}$
  - μ = mean (correction factor)

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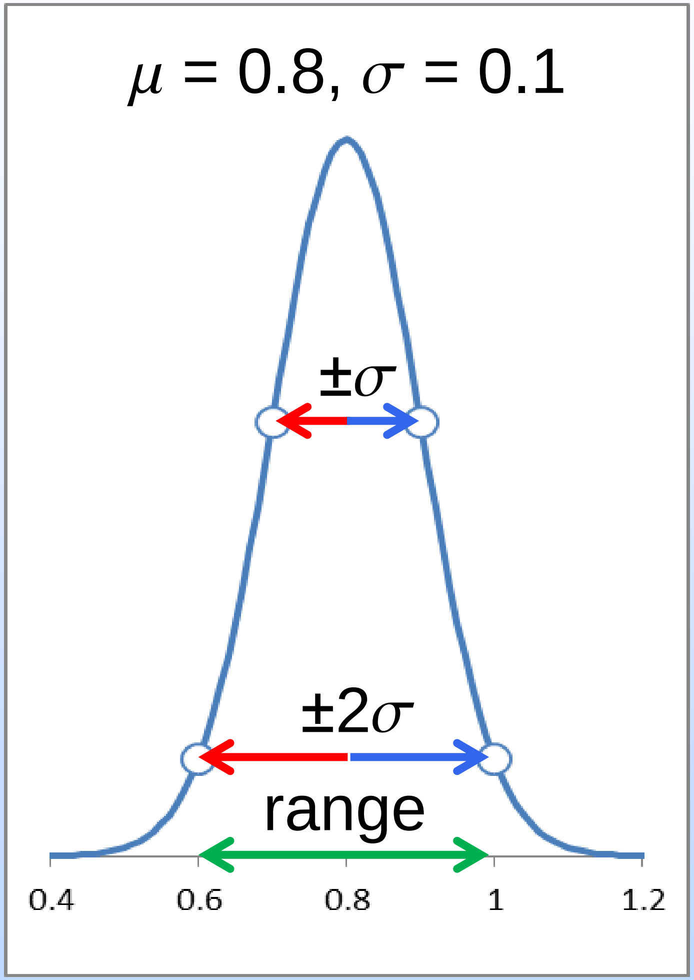
Estimating error as normal distribution



- If standard deviation, σ is known, use it.
- If range of possible values is known, then approximate

$$2\sigma = ½ \text{ range}$$

- Assigns *probability* of actual value
- Example
  - For range = 0.4, σ = 0.1

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Approximating source to skin distance (SSD) uncertainty as a normal distribution

Assigned SSD (cm)	Estimated range of error	Estimated range of correction factors	Estimated range of relative uncertainty	Estimated σ
60 (AP)	±2 cm	0.93 to 1.07	± 0.07	0.035
60 (AP)	±5 cm	0.85 to 1.15	± 0.15	0.075
60 (Lat)	±10 cm	0.7 to 1.3	± 0.30	0.15

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Propagation of normalized error

- For a composite correction factor, $\mu_c = \prod_i^I \mu_i$, assume that the normalized errors are uncorrelated and then combine variances by the delta method
  - $\sigma_c{}^2 = \sum_i^I \sigma_i{}^2 \cdot [\prod_{j \neq i}^J \mu_j]^2$
  - $\sigma_c = \left[\sum_i^I \sigma_i{}^2 \cdot [\prod_{j \neq i}^J \mu_j]^2\right]^{1/2}$

↑

Partial derivative of μ_c with respect to μ_j, where μ_c is the composite correction factor

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Propagation of normalized error

- Assign an a reasonable normalized error to each correction factor.
  - Measured error
  - Range estimate
- Calculate the estimated composite error.
- The largest 1 or 2 single sources of error will dictate the magnitude of the composite error.
  - Identify and correct the largest sources of uncertainty to improve the precision of the skin dose estimate.

Single exposure error estimate

- For every estimate of skin dose, D_f (x, y, z)
  - $D_f(x, y, z) = K_f \prod_i^I \mu_{f,i}$
  - $\sigma_f = K_f \, \sigma_c = K_f \left[\sum_i^I {\sigma_i}^2 \cdot \left[\prod_{j \neq i}^J \mu_j \right]^2 \right]^{1/2}$
  - where *f* is the exposure event
  - and *K* is the air-kerma

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Multiple exposure error propagation

- The same (or similarly derived) correction factors are used to calculate dose (D) for each exposure event (f).
- Therefore, the dose events are assumed to be highly correlated.
- Traditional “square root of the sum of the squares” error propagation assumes measurements are independent and is therefore incorrect.

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Multiple exposure error propagation

- Sum the dose (D) from all exposures.
  - $D(x,y,z) = \sum_f^F D_f$
- Propagate error from all exposures.
  - $\sigma_D{}^2 = \sum_f^F \pm\sigma_{D,f}{}^2 + \sum_{f_i \neq f_j}^F \left[\sigma_{D,f_i}{}^2 \cdot \sigma_{D,f_j}{}^2\right]^{1/2}$

↑ Covariance matrix diagonal elements

↑ Covariance matrix off-diagonal elements

- The composite variance is the sum of the elements of the auto-covariance matrix of the individual dose error estimates.

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Peak skin dose reporting

- For every estimate of skin dose, $D(x, y, z)$
  - Report a nominal expectation value D
  - Report the 95% CI associated with D
    - 95% CI = $D \pm 1.96\,\sigma$

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Sample statement for patient record

"The interventional procedure performed on patient Austin Texas on 7-23-2014 had an estimated peak skin dose of 4.5 Gy (95% CI: 3.4 to 5.6 Gy)."

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Summary

- Recognize sources of error associated with skin dose estimates.
- Reduce bias errors to random errors.
- Assign realistic error estimates to all correction factors.
- Report the expected skin dose and an estimated range of possible values.