Uncertainty in Radiation "Dose Reconstruction" from Medical X-Rays

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[Enormous] Uncertainty in Radiation “Dose Reconstruction” from Medical X-Rays

Purpose: Broad Overview

- Context: “Dose Reconstruction”
- Dependence of dose (that would have been causal to various cancers) on various parameters
- Degree of knowledge of those parameters
  - what’s known and what’s assumed
  - uncertainty in assumptions made in absence of evidence
- Postulated nature of uncertainty parameters
  - ISO GEUM Type A or Type B?
  - Random or systematic for an individual
- Dosimetry, Dosinference, and Doswaggery
- The Future: Monte Carlo uncertainty propagation

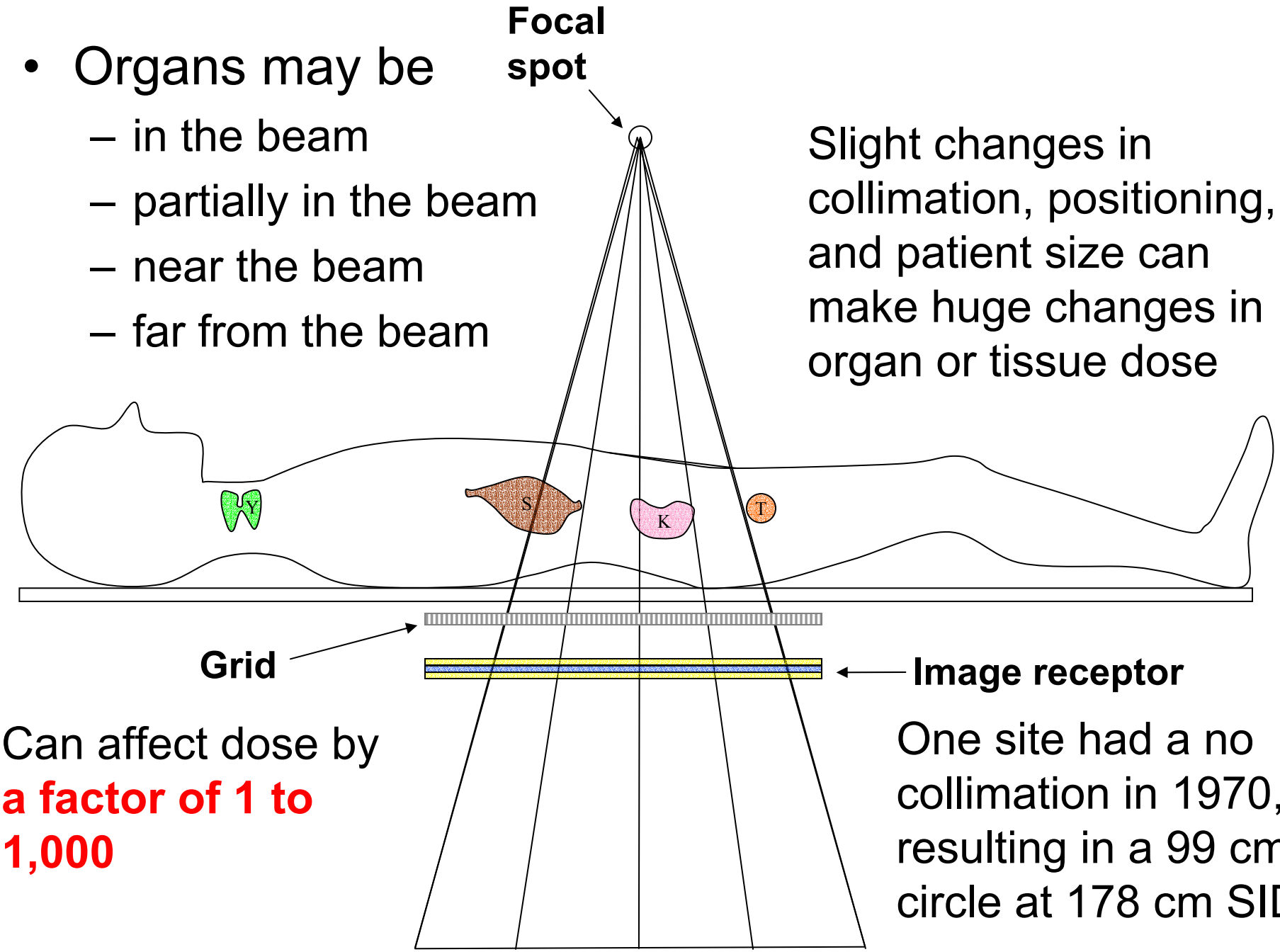
Technique and X-Ray Machine Characteristics Affect Tissue or Organ Dose

- Characteristics of the X-ray machine
  - Inherent & added filtration: **×4 (100 kVp), ×10 (45 kVp)**
  - Waveform (type of rectification): **×1.7**
  - Type of target (e.g., tungsten): (74/42) = 1.76 (usu. **×1**)
  - Condition of the target: **×1.5**
- "Technique"
  - Source-to-image distance (SID), source-to-skin distance (SSD): **×2**
  - Accelerating potential (kilovolts peak): $\propto(\text{kVp})^{2.0\text{-}2.5}$; **×2**
  - Timer error: **×2 or more**
  - Charge used in each exposure, expressed as the product of exposure time(s) and tube current (mA), in mAs (or mC): $\propto$**(mAs)^1**; see below

Other Factors Affecting Dose to Tissue or Organ

- Projection, e.g., anterior-posterior (AP) lumbar spine
- Degree to which the beam was collimated: **×1,000**

- Organs may be
  - in the beam
  - partially in the beam
  - near the beam
  - far from the beam



Slight changes in collimation, positioning, and patient size can make huge changes in organ or tissue dose

Can affect dose by **a factor of 1 to 1,000**

One site had a no collimation in 1970, resulting in a 99 cm circle at 178 cm SID

Other Factors Affecting Dose to Tissue or Organ

- Projection, e.g., anterior-posterior (AP) lumbar spine
- Degree to which the beam was collimated: **×1,000**
- Actual or probable number of retakes: **×2**
- Frequency of examination, e.g., annually : **×3**
- Method used to assign doses: **×3 or more**
  - Rosenstein 1976 (incarnated as ICRP Pub. 34, 1982)
  - Rosenstein 1988 http://www.fda.gov/cdrh/ohip/organdose.html
  - NRPB's SR-262 http://www.nrpb.org/publications/software/sr262.htm#r262
  - Finland's PCXMC http://www.stuk.fi/pcxmc/

Effects of Patient and Hardware Characteristics on Doses

- Patient characteristics (i.e., thickness of the part X-rayed): **×3.5** for lumbar spine (LAT) with 36” SID
- The projection: You can’t reconstruct dose without this!
  - Chest, Lumbar Spine, etc.
  - AP, LAT, PA, etc.
- Whether a Potter-Bucky moving grid was used: **×6**
  - if so, the type of grid (focused or unfocused, grid ratio)
- The type of film or image receptor used
  - conventional radiography v. photofluorography: **×100**
  - Film and screen combination (Bates 1969)
    - For a given screen, doses to produce O.D. = 1.0 range over a **factor of 3.4**, CV = 34%, GSD = 1.41
    - If screen is unknown, doses range over **a factor of 15.2**, CV = 67%, GSD = 2.04
- How the film was developed: **×2** or more

What Is Known and What Is Assumed

- Measurements can dramatically reduce uncertainty
  - Measurements don’t apply to individuals
  - Individual variability still remains
- The existence of a usable film places limits on some parameters
  - doesn’t tell about collimation, filtration, film/screen, retakes, patient thickness

Honestly Naming What We Do: Dosimetry, Dosinference, and Doswaggery

- Dosimetry
  - “dose” + metry; root metron, Greek, to measure
  - ***measurement*** uncertainty dominates
- Dosinference (Strom 2002)
  - blend of “dose” + “inference”
  - ***inferential uncertainties*** >> measurement uncertainties
- Doswaggery (Strom 2002)
  - blend of “dose” + “swag” acronym: *scientific wild assumption guess* (US popular usage)
    - predicting the weather two weeks in advance
    - predicting the value of the stock market in a year
  - ***assumption uncertainties*** >> inferential uncertainties >> measurement uncertainties (if there were any measurements!)

Conclusions

- IF you know
  - trustworthy measurements were made
  - techniques
  - film, screen, developer, collimation, filtration
  - patient thickness
  - projections, # of retakes

  you can limit some of the uncertainty
- IF you don't, it's doswaggery
- A Monte Carlo approach is needed

References: Please e-mail strom@pnl.gov for a copy

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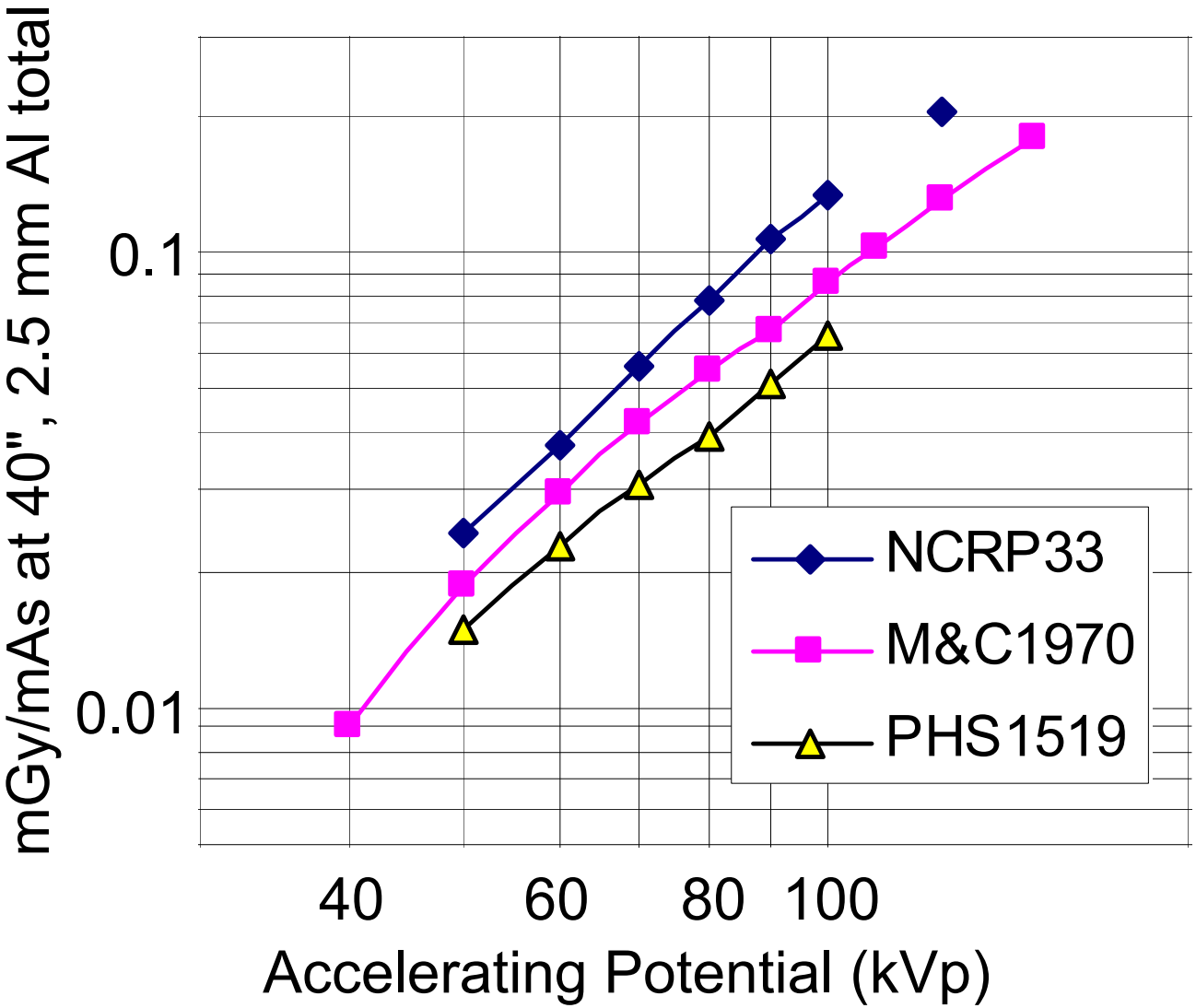
The following slides were deleted from the presentation at HPS due to time constraints.

These slides illustrate conclusions presented in the talk.

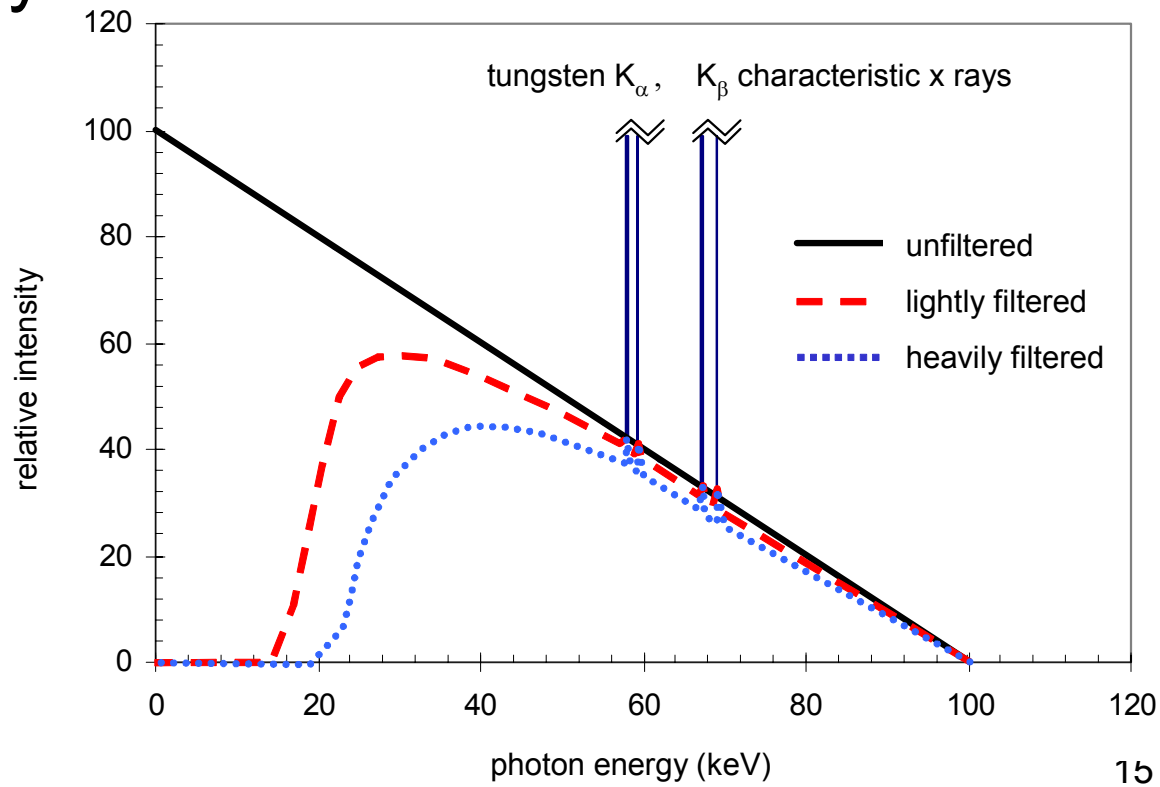
Variation of X-ray Output with Accelerating Potential

- Increases at $kVp^{>2}$ (Kramers 1923)
- Varies by more than **a factor of 2** among authors



Effect of Inherent and Added Filtration

- More filtration: radiation is more penetrating
- Less filtration: radiation is less penetrating
- What is constant?
  - equivalent quality images; or
  - a fixed, known technique (kVp, mAs, SID) ?

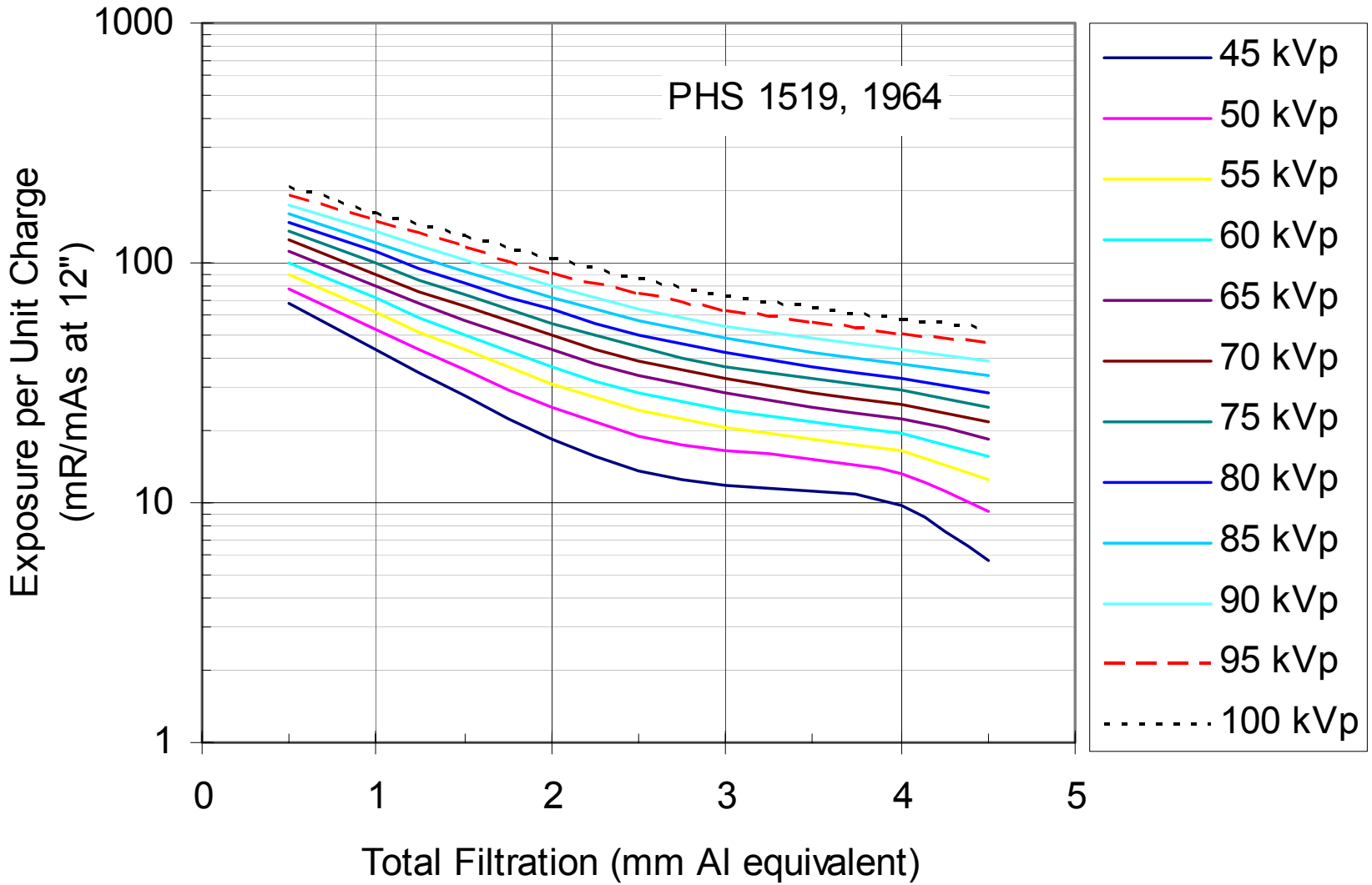


Effect of Inherent and Added Filtration

- More filtration: radiation is more penetrating
  - the ESE is lower for a given image quality
  - deeper tissues get a larger fraction of ESE
  - distal tissues get a larger fraction of ESE
- Less filtration: radiation is less penetrating
  - the ESE is higher for a given image quality
  - tissues in primary beam, especially those closer to the target, get higher doses than they would with more filtration
- Therefore, for equivalent quality images produced using an unknown technique, assuming
  - more filtration yields larger doses to distal tissues
  - less filtration yields larger doses to tissues in primary beam
- For a fixed, known technique (kVp, mAs, SID), assuming
  - more filtration results in lower doses to tissues in primary beam and higher doses to distal tissues
- Which assumption yields the highest dose per film depends on where the target tissue is!

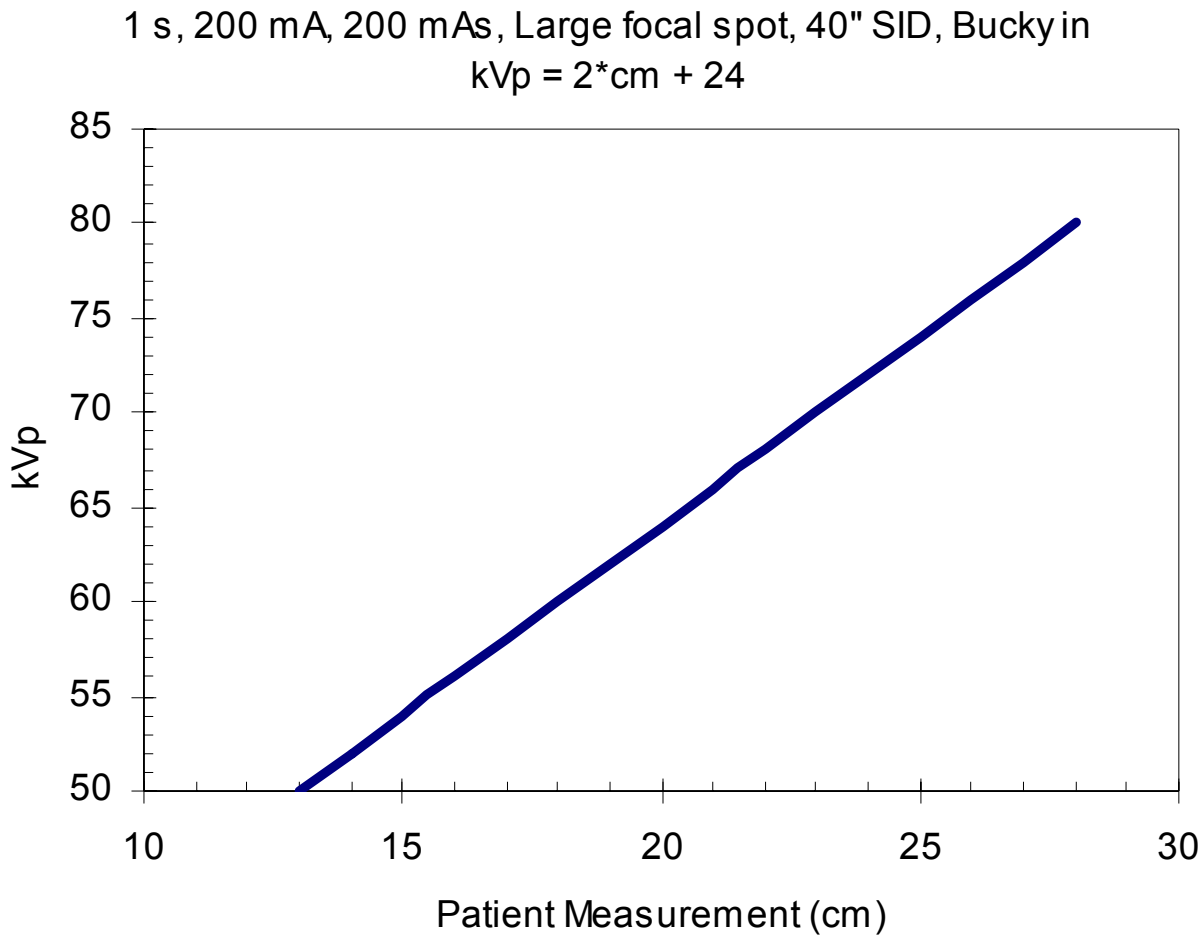
Variation in X-ray Output with Accelerating Potential and Total Filtration

- Filtration changes output by ×**4** (100 kVp), ×**10** (45 kVp)



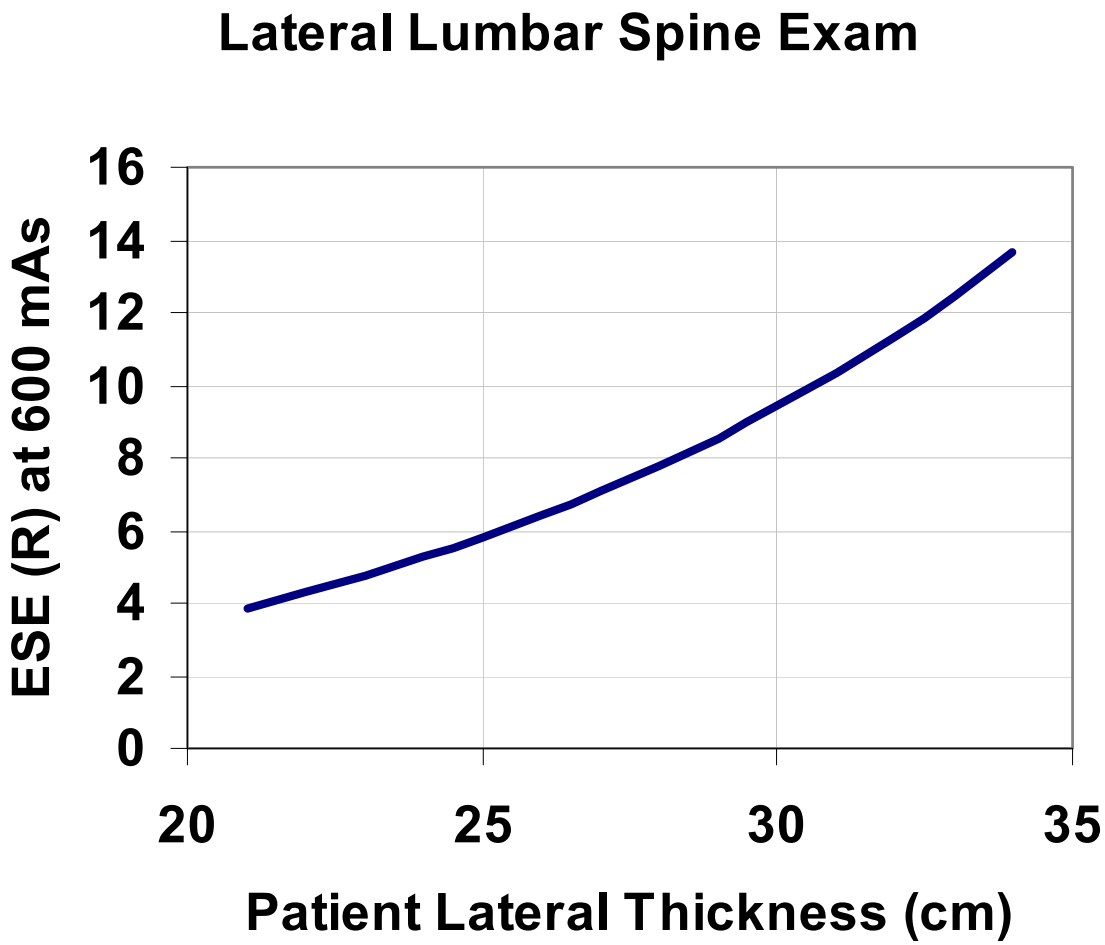
Effect of Patient Thickness

- More radiation and more penetrating radiation is needed to produce a quality image
  - generally, higher kVp is used



Effect of Patient Thickness

- Entrance skin exposure (ESE) can increase rapidly with thickness
  - For a given source-to-image distance (SID), the skin of a thicker patient is closer to the source
  - This is just geometry; it ignores the need for more radiation!
  - A factor of **3.5** for lumbar spine (LAT) with 36” SID



Effect of Collimation - 1

- This effect can be **truly enormous**
  - Tissues at edge of beam
  - Tissues partially in primary beam
  - Tissues not listed in old method
    - EEOICPA tissues do not correspond to
      - Rosenstein 1976 (ICRP 34)
      - Rosenstein 1988 (CDRH web site)
      - U.K. National Radiological Protection Board (NRPB) SR-262
      - Finland's STUK PCXMC

Cancers for Which Doses Might Be Needed: This Doesn't Look Like ICRP's List!

- Acute lymphoid leukemia
- All digestive
- All male genitalia
- All male genitalia AND All urinary organs (if male)
- Bladder
- Bone
- Breast
- Colon
- Esophagus
- Eye
- Female genitalia, less Ovary
- Female genitalia, less Ovary AND Ovary
- Female genitalia less Ovary And Ovary AND All urinary organs (if female)
- Gall bladder
- Leukemia, less CLL
- Leukemia, less CLL AND Acute lymphoid leukemia, AND Acute myeloid leukemia
- Leukemia, less CLL AND Acute myeloid leukemia
- Liver
- Lung
- Lung AND Other respiratory
- Lymphoma and multiple myeloma
- Malignant melanoma
- Malignant melanoma AND non-melanoma skin
- Malignant melanoma AND Non-melanoma skin-Basal cell
- Nervous System
- Non-melanoma skin-Basal cell
- Oral cavity and pharynx
- Other and ill-defined sites
- Other endocrine glands
- Other Respiratory
- Ovary
- Pancreas
- Rectum
- Stomach
- Thyroid
- Thyroid AND Other endocrine glands
- Urinary organs less bladder

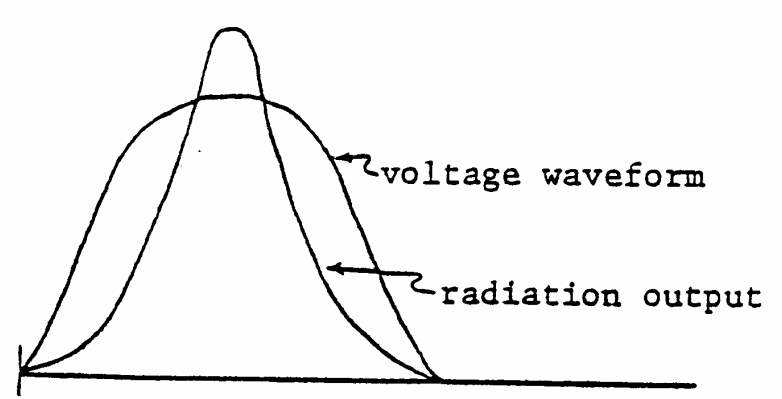
Adapted from Table 4, pp. 47-52, NIOSH-IREP Technical Documentation, June 18, 2002

Effect of Collimation - 2

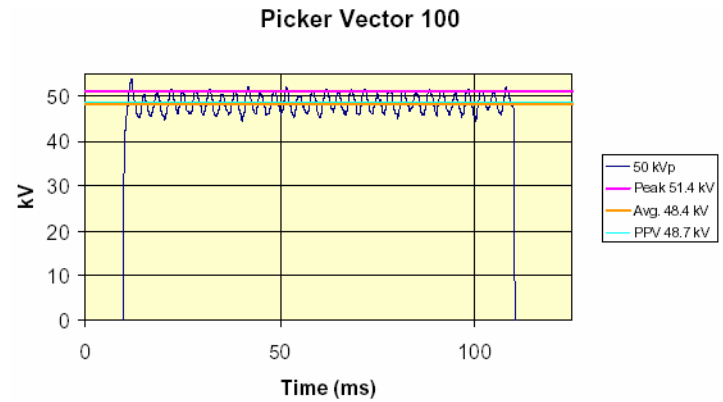
- This effect can be truly enormous (×1000) for tissues that were in the primary beam but were assumed not to be!
- Example at one facility in 1970
  - circular cone, not rectangular
  - measured beam diameter = 99 cm at 178 cm SID
  - a 36 cm × 43 cm (14” × 17”) film requires 56 cm
  - 99 cm includes head, gonads, and all of abdomen
- Standard methods of dose assessment are *worthless* for this collimation
  - Rosenstein 1976 (=ICRP Pub. 34)
  - Rosenstein 1986
  - NRPB SR 262
- Only STUK’s PCXMC can handle this

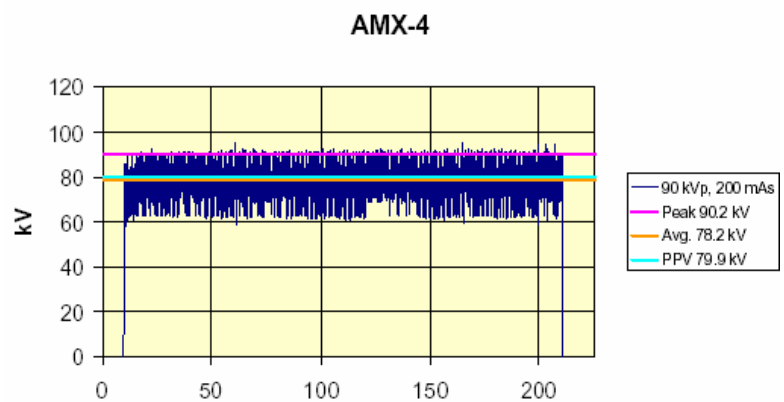
Effect of Waveform

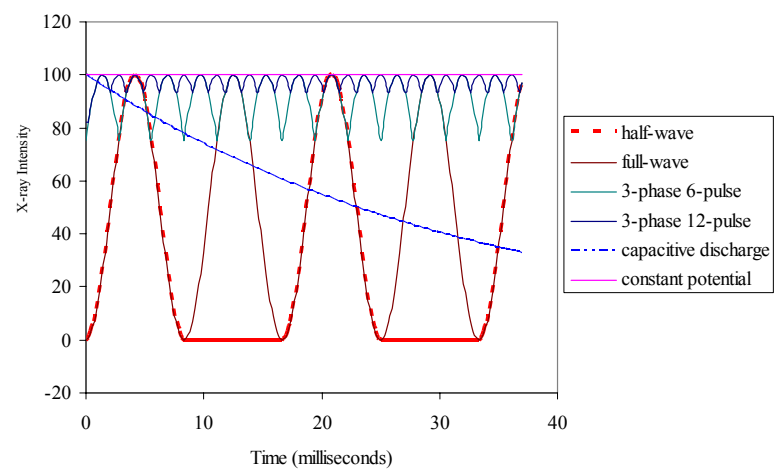
- For single-pulse (full-wave or half-wave rectified) x-ray generators, most of the dose comes in sharp pulses due to kVp^2 an absorption of low-energy photons

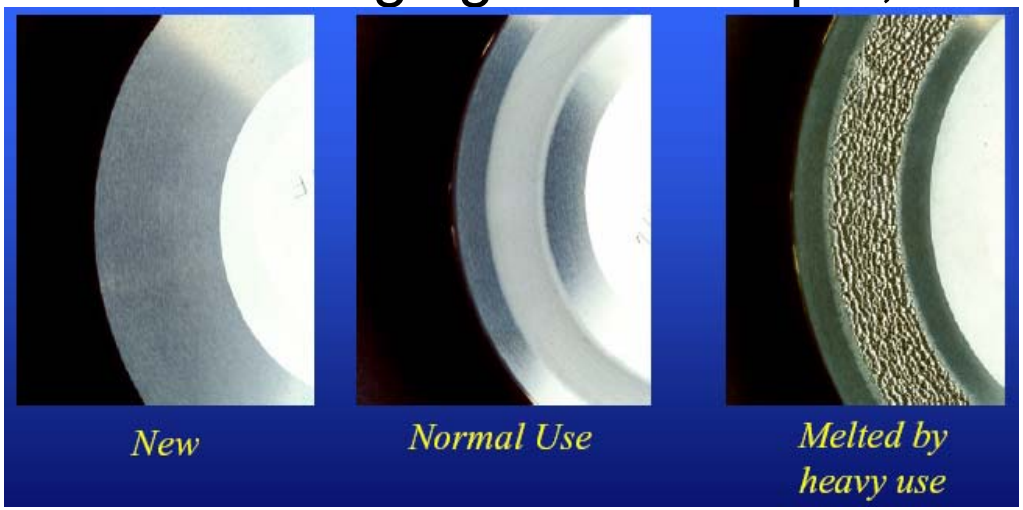
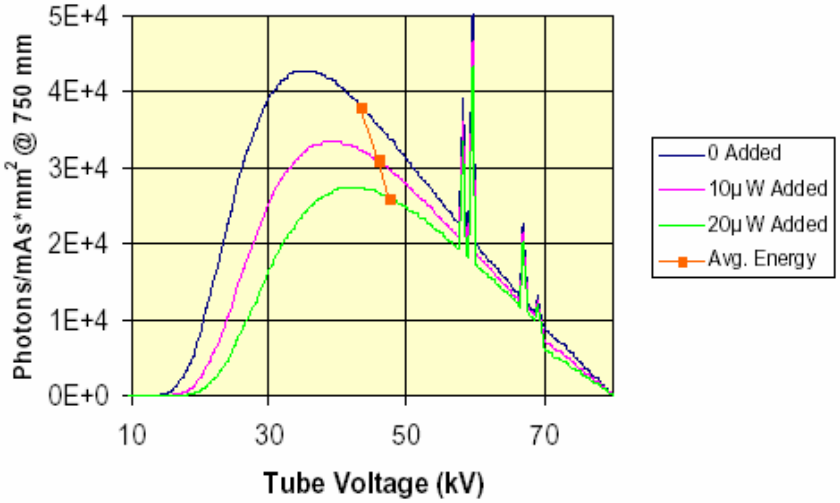


- Small changes in kVp make a disproportionate change in radiation







Film and Screen Combination; Film Quality and Developing; Anode Aging

- Film and screen combination (Bates 1969)
  - For a given screen, doses to produce O.D. = 1.0 range over a **factor of 3.4**, CV = 34%, GSD = 1.41
  - If screen is unknown, doses range over a **factor of 15.2**, CV = 67%, GSD = 2.04
- Film Quality
  - Poor quality has caused high doses
- Exhausted chemicals cause high doses
- Anode aging: lower output, harder spectrum (Sunde 2004)