Radiation Exposure in **Diagnostic Imaging**

Fact or Fiction

Image Wisely
Image Gently

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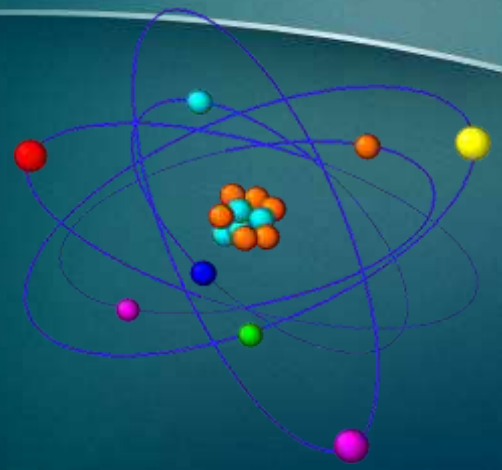
Past President – **Society for Pediatric Radiology**

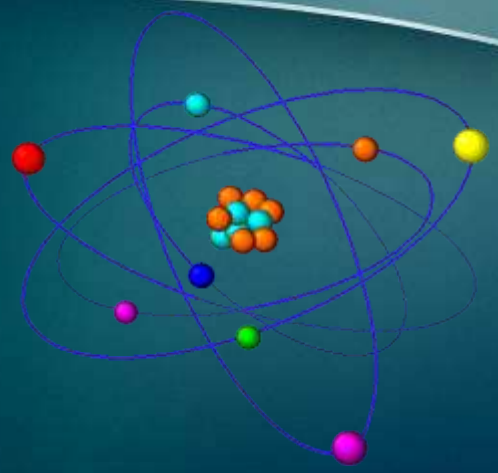
Objectives



- Achieve an understanding of:
  - Ionizing radiation
  - Units used to measure ionizing radiation
  - Effects of ionizing radiation
  - Radiation considerations in Diagnostic Imaging
  - Applications of the ALARA principle in Diagnostic Imaging

Background

Ionizing Radiation

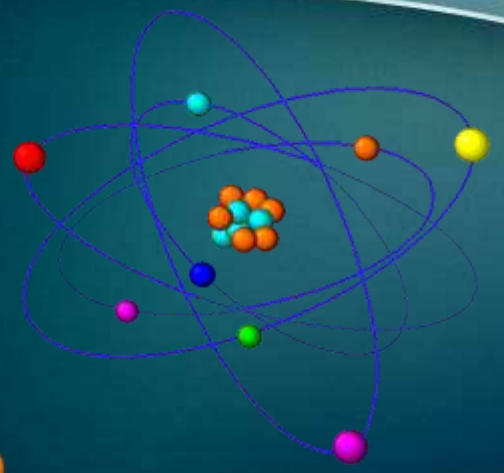


What is Ionizing Radiation?

- Particles *or* electromagnetic waves
- Sufficiently energetic
  - Detach electrons from atoms or molecules

Background

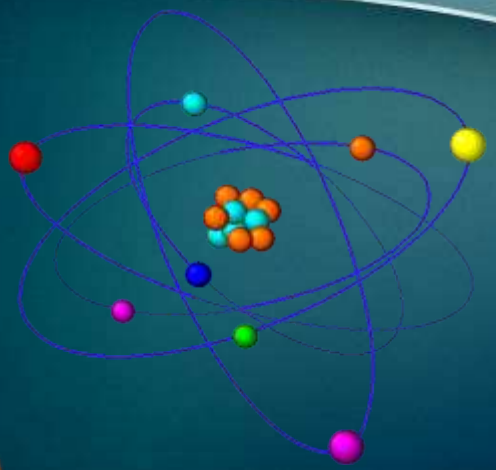
Ionizing Radiation



- Alpha particles
- Beta particles
- Neutron
- Gamma rays
- X-rays

Background

Ionizing Radiation

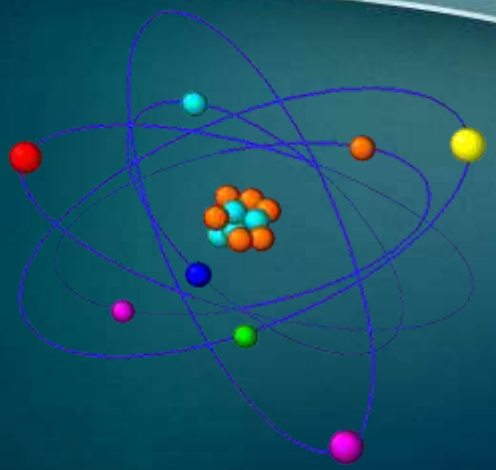


- Alpha particles

  - Doubly-ionized helium nucleus (He^{++})
    - Highly ionizing
    - Low penetration (if result of radioactive decay) ≈ 5MeV
      → Stopped by skin or few centimeters of air
    - Very problematic if inhaled or ingested

Background

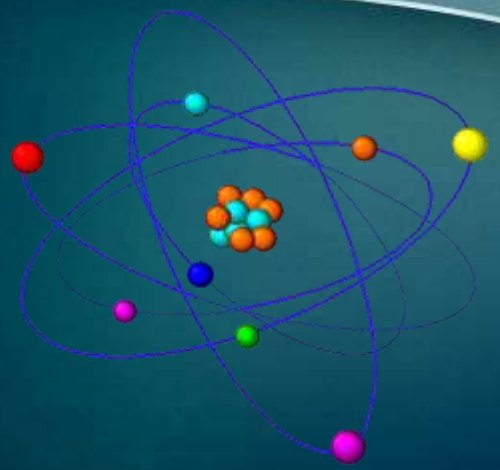
Ionizing Radiation



- Beta particles → - / +
  - Electron or Positron
    - Less ionizing than alpha particles
    - 100 times more penetrating than alpha particles

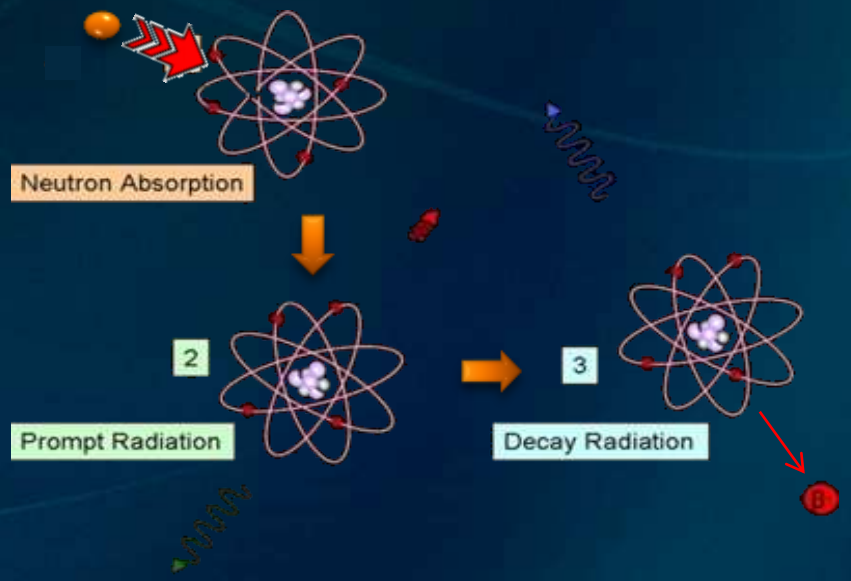
Background

Ionizing Radiation



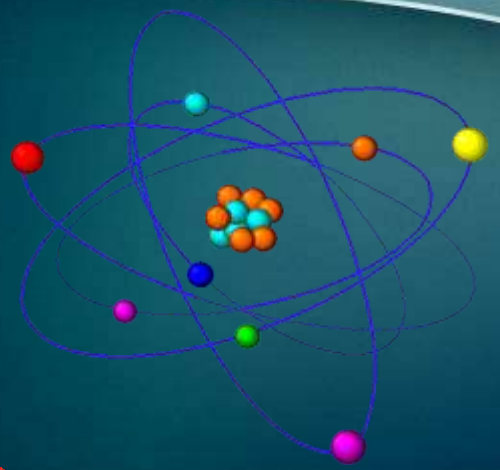
- **Neutron particle**

  - **Usually result of nuclear fusion/fission reactions**
    - **No intrinsic charge**
    - **Interact with tissues**
      - → **neutron absorption**
      - → **gamma release**
      - → **capture by tissue nuclei**



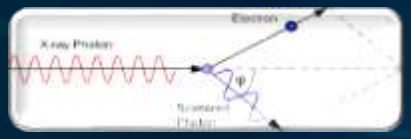
Background

Ionizing Radiation



- Gamma rays
- X – rays

- Compton effect
  - Ionization of atom with change in incident λ

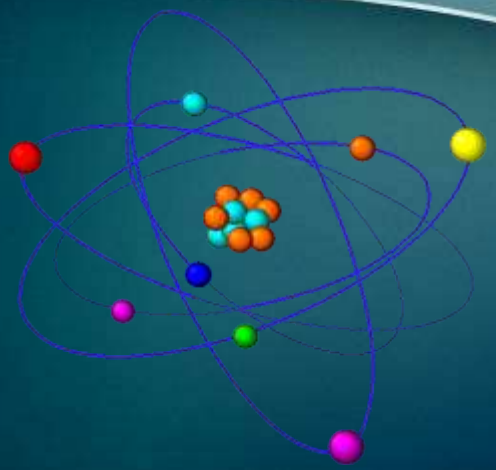


- Photoelectric effect
  - Photon ejects electron from host atom

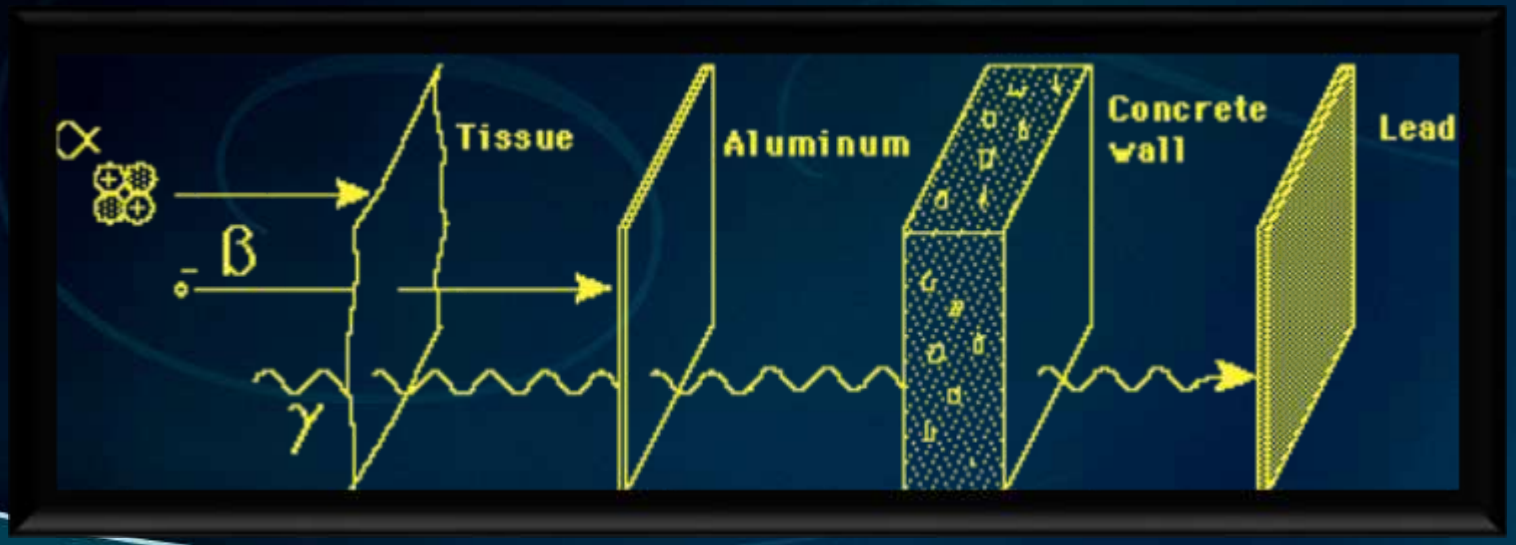
- Pair production
  - Production of electron and positron

Background

Ionizing Radiation

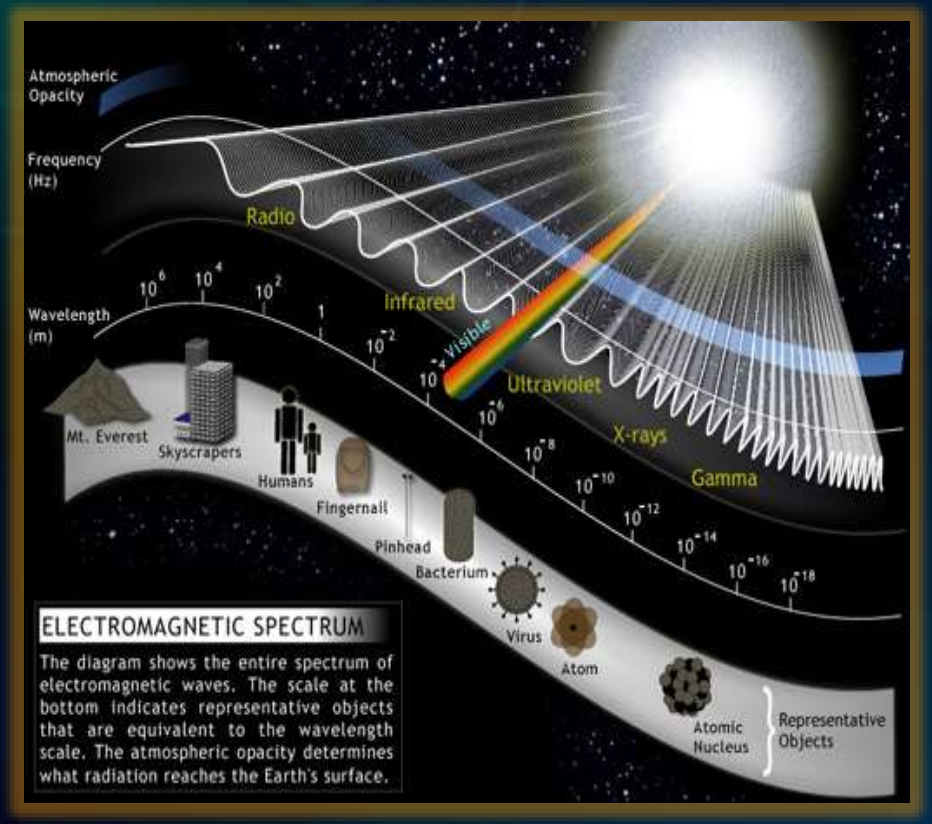


- **Relative penetration**



Background

Ionizing Radiation

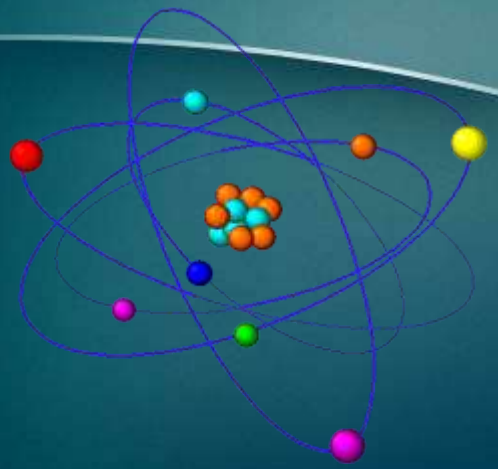


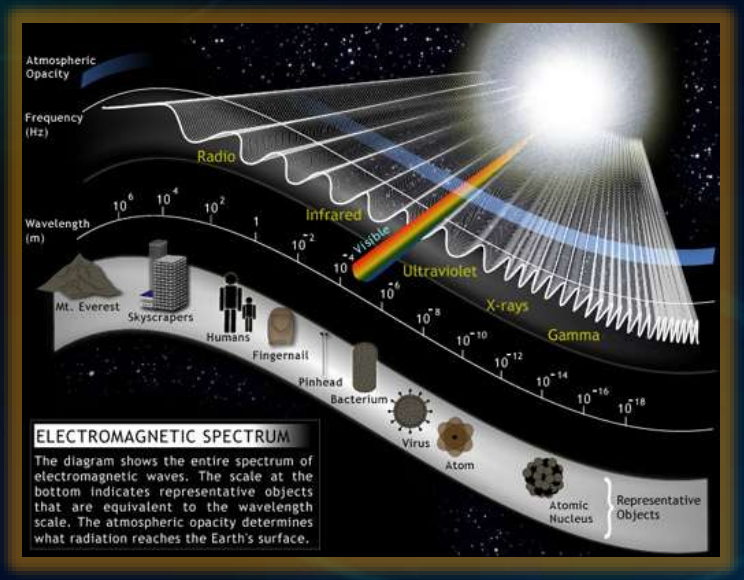
- $v = f \times \lambda$
  - $v = c$ in vacuum
  - $f = c/\lambda$
- $E = h \times f$
  - h = Planck's constant
- Relative energies
  - Radio waves: 1×10^{-6} eV
  - Visible light
    - Red 1eV
    - Blue 3eV
  - X rays: 50,000 eV

UC Berkeley: ds9.ssl.berkeley.edu

Effects of Radiation

Ionizing Radiation

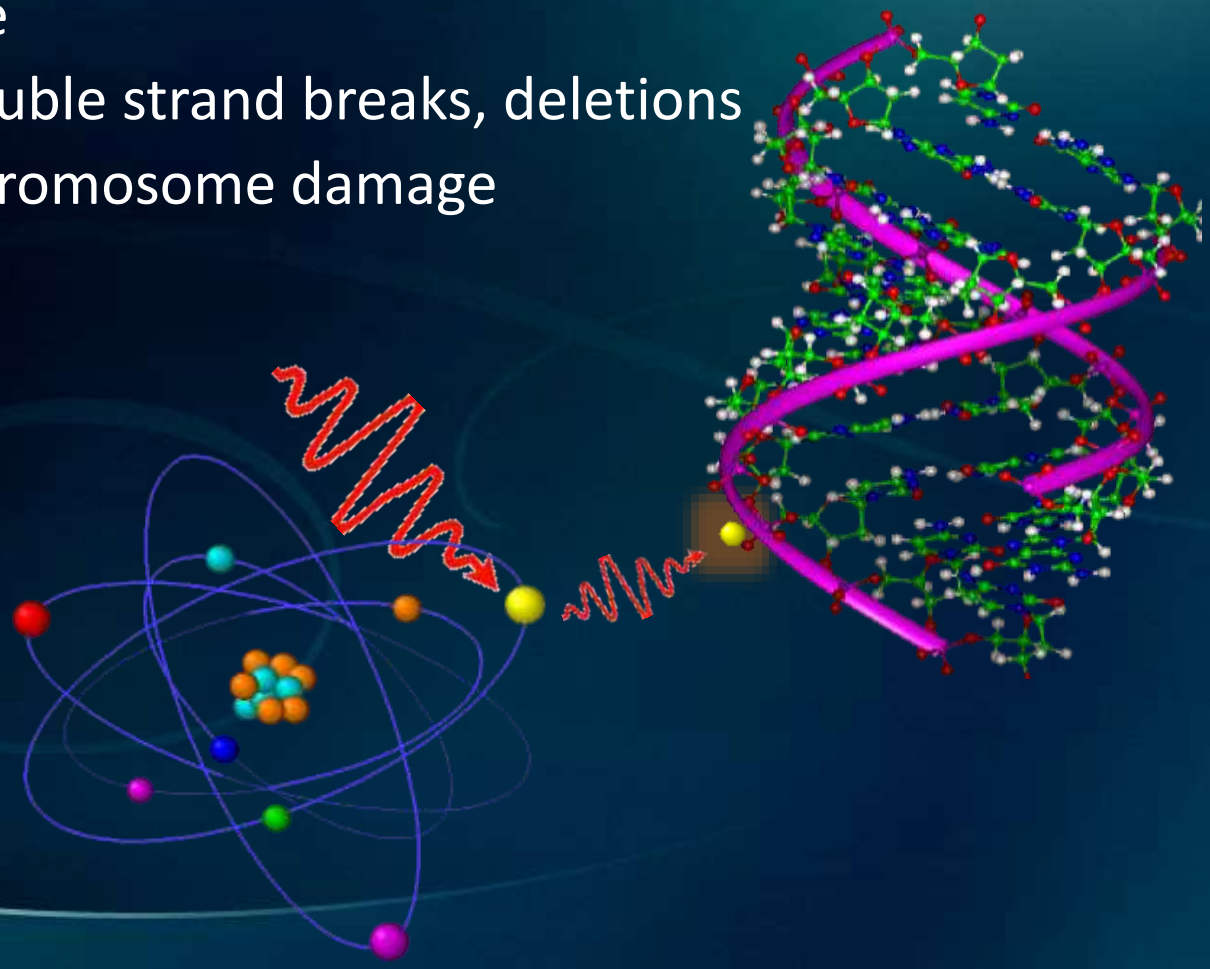




- No damage
- Cellular Damage
  - Repair (Hours)
    - → Operate normally
    - → Operate abnormally
      - √ Carcinogenesis
      - √ Genetic alterations
- Death

Effects of Radiation

- Ionizing radiation
  - Oxidative changes in nucleotide bases
  - DNA damage
    - Single, double strand breaks, deletions
  - Gene and chromosome damage



Effects of Radiation

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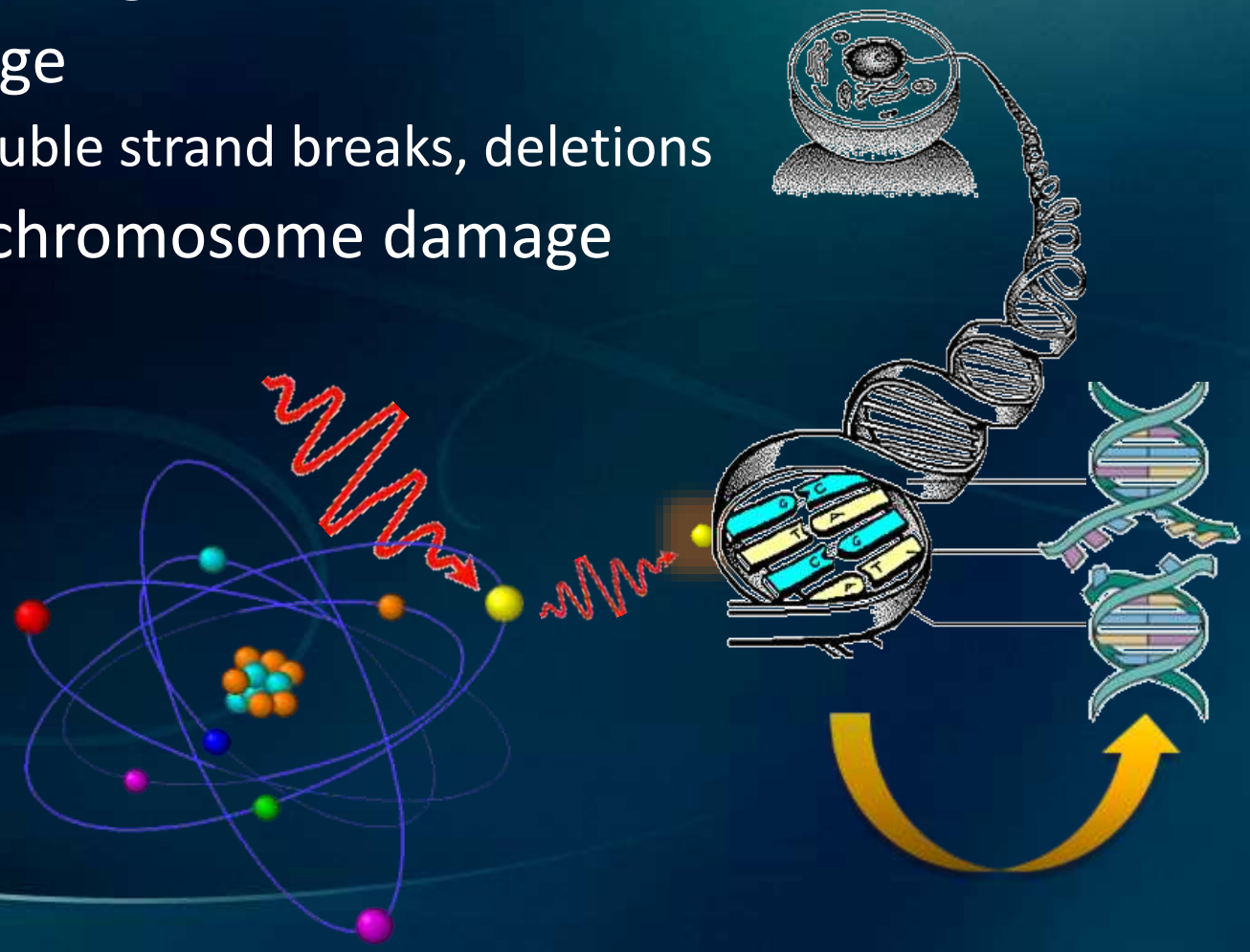
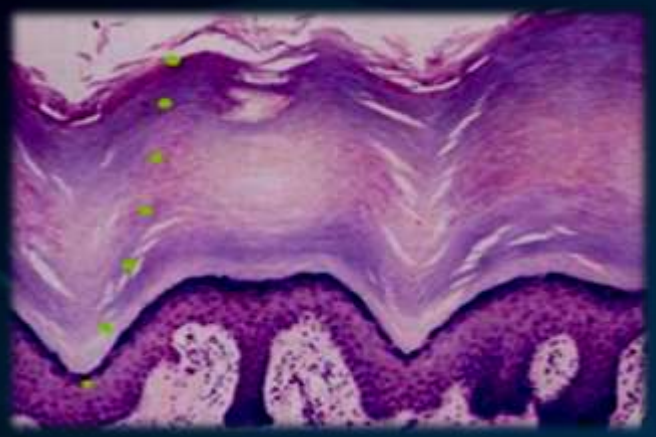
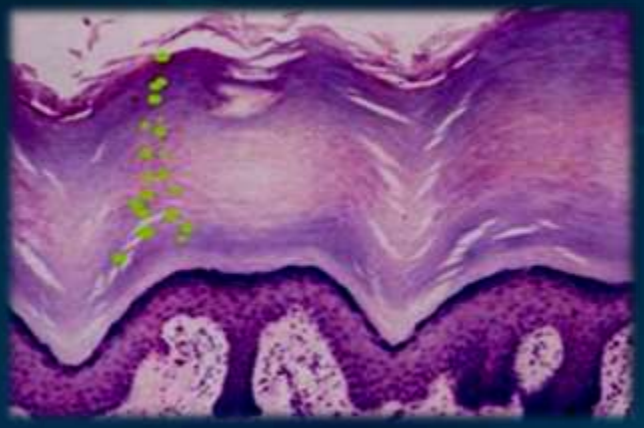


Effects of Radiation

- LET
  - Linear Energy Transfer:
    - Rate at which energy is transferred from ionizing radiation to tissue
      - → Low LET: Xrays, Gamma rays: RBE (QF) = 1
      - → High LET: particles, such as alpha particles: QF 20



X - rays



α particles

http://www.ceessentials.net

Measurements

- Units
  - **Roentgen**
    - Only applies to photons in air
  - **RAD** (Roentgen-Absorbed-Dose)
    - Unit of absorbed dose in tissue
    - **1 Roentgen = 1 Rad**
  - **REM** (Roentgen-Equivalent-Man)
    - Accounts for biological effect of *type* of radiation,
    - Quality Factor (QF) or Radiation Weighting Factor (RWF)
    - For Xrays, QF = 1; rad = rem
    - **For alpha particles, QF = 20**

QF

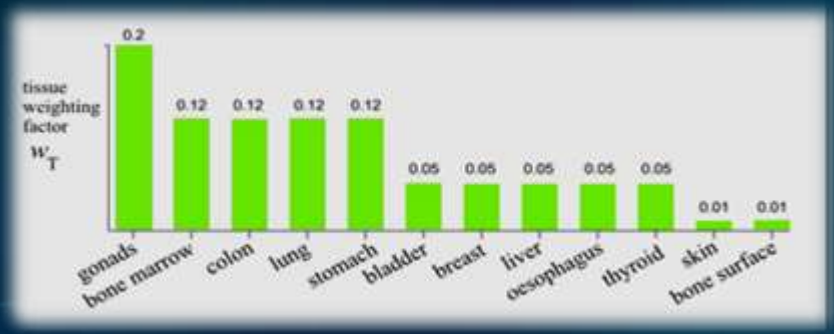
X rays	1
Gamma rays	1
Beta particles	1
Neutrons (depending on energy)	5-20
Alpha particles	20

Measurements

- SI (Système Internationale) Units
  - Gray: = Absorbed Dose;
    - 1 Gray = 100 rads; 1mGy = 0.1 rad
  - Sievert: Dose Equivalent;
    - 1 Sievert = 100 rem; 1 mSv = 0.1 rem

Measurements

- Units
  - Effective Dose:
    - Takes into account the radiation sensitivity of organs exposed (W_T)
      - → Most sensitive: **Growing tissues**; lymphocytes, spermatogonia
      - → Least sensitive: Muscle, nerve
    - Equivalent risk to the whole body
      - → Measured in rem or Sieverts

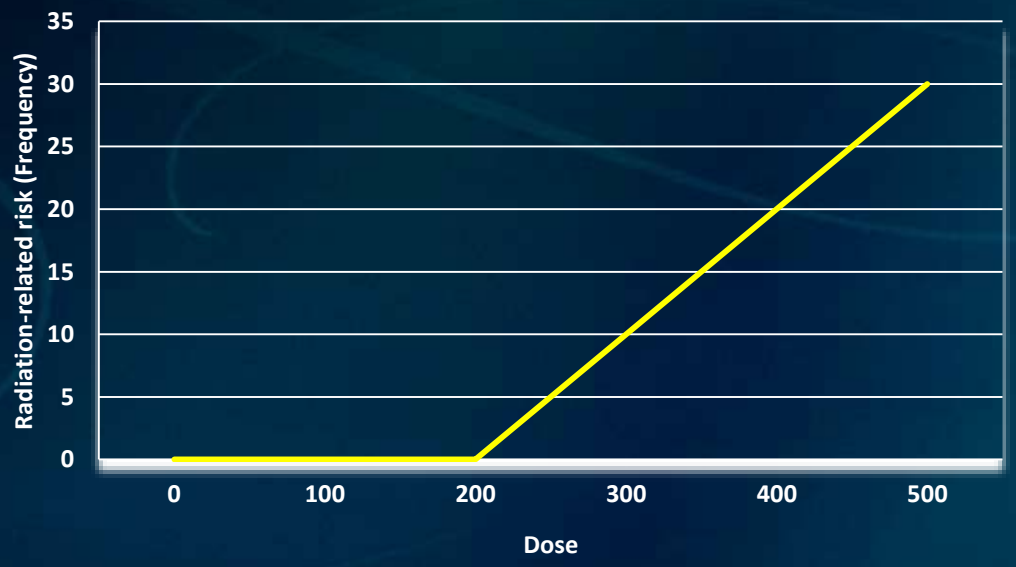


Effects of Radiation

- Deterministic
- Stochastic

Deterministic

- Threshold: +
- Dose-dependent
  - Skin erythema
  - Depilation
  - Death



Effects of Radiation

Deterministic

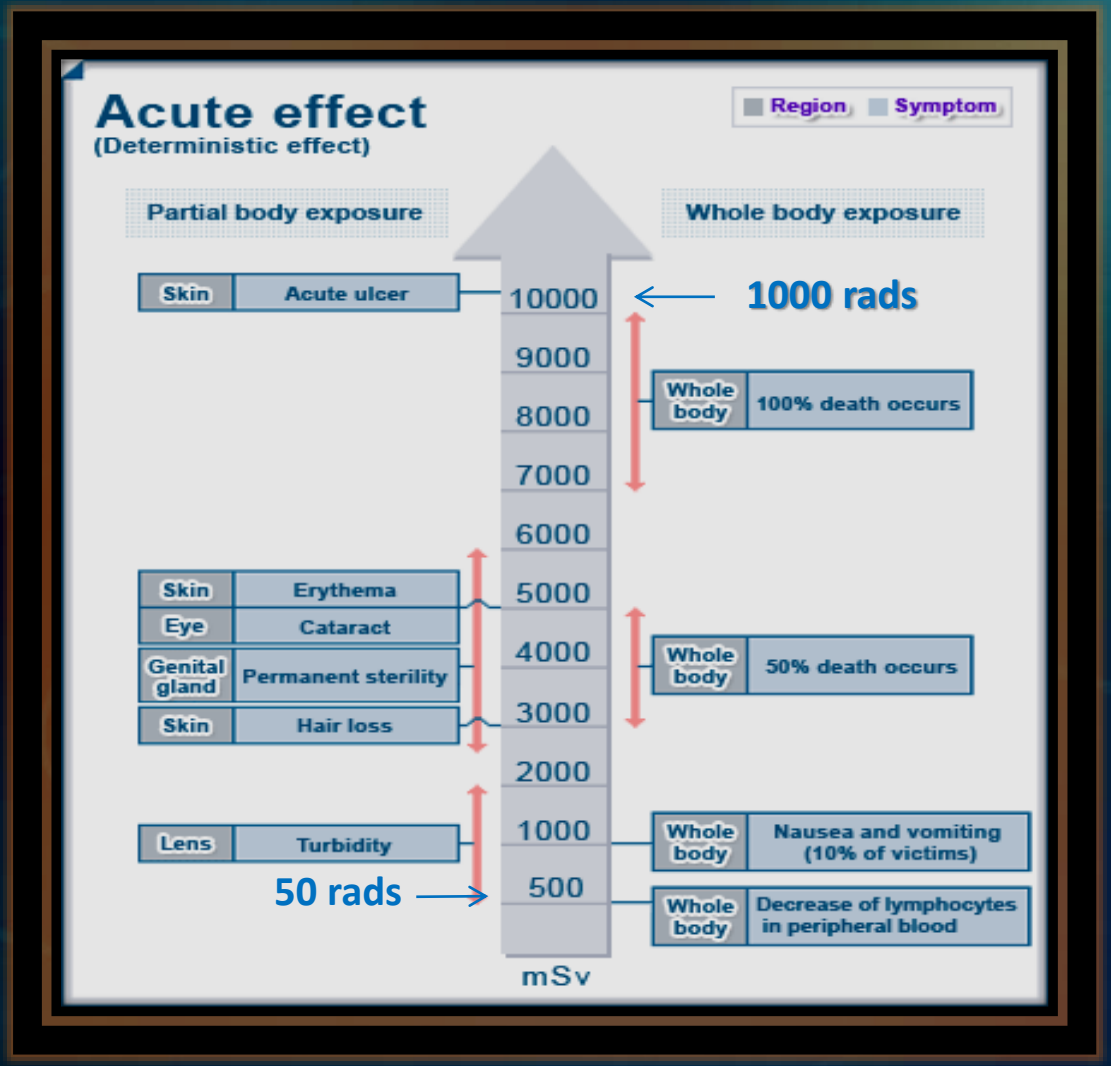
Erythema
2-3 Gy

Epilation
Temporary 3Gy
Permanent 5 Gy

Desquamation
Ulceration
10-15 Gy

Acute 1 – 2 Gy
Cataracts

Dose Response: Humans: Acute exposure

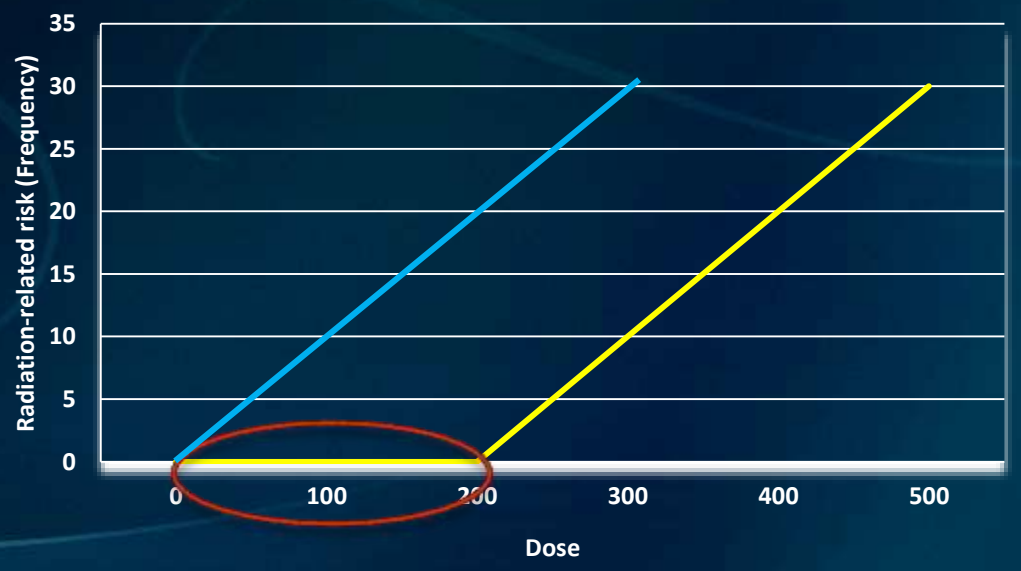


www.jaeo.go.jp

Effects of Radiation

Stochastic

- LT Model
- LNT Model
- Dose-independent severity
- Dose-dependent probability
  - Cancer
  - Hereditary changes

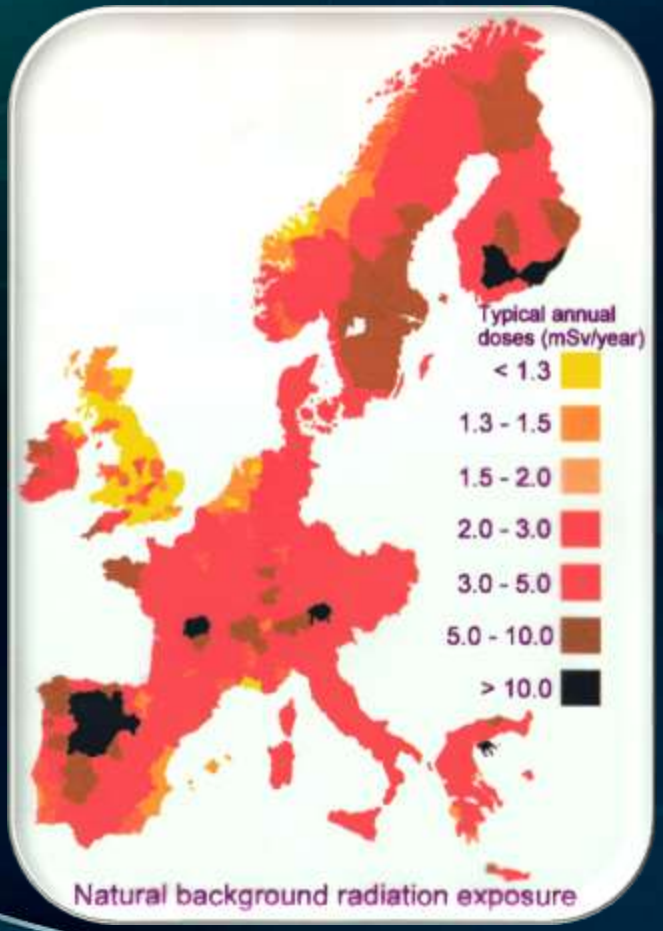


Background Radiation

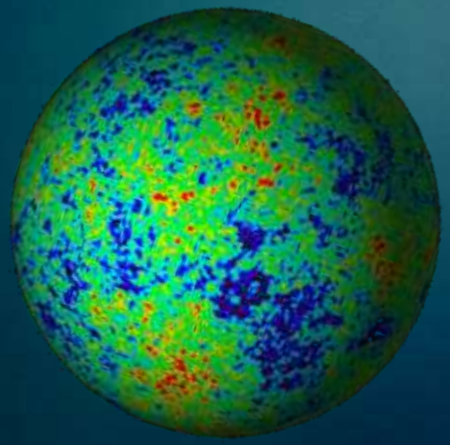
“Natural” Sources

≈ 3mSv / year near sea level

Background Radiation



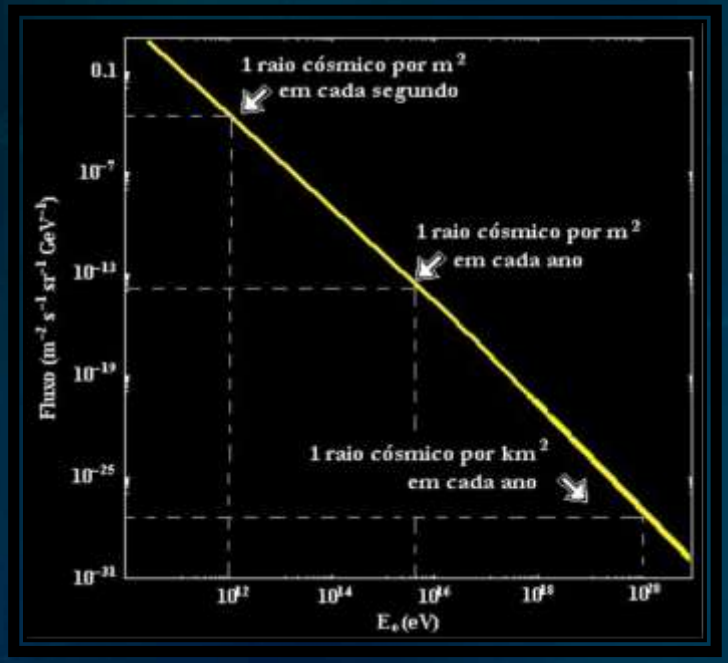
http://www.world-nuclear.org/info/Safety



- Average for US @ sea level
  - 3mSv/year
- At 5,000 ft (Denver, Boulder)
  - 5 – 6 mSv/year
- Cross-country flight (USA)
  - 0.04 mSv (https://www.sievert-system.org/#Calcul)

Background Radiation

- "Natural" Sources
  - Radon
    - Derived from Uranium and Radium
      - → Decays through emission of α particles
        - √ Isotopes of polonium, lead, bismuth
  - Cosmic "Rays"
    - Particles
      - → 89% nuclei of hydrogen,
      - → 10% nuclei of helium (α particles)
      - → 1% heavier atoms
  - Food Chain (C^{14})



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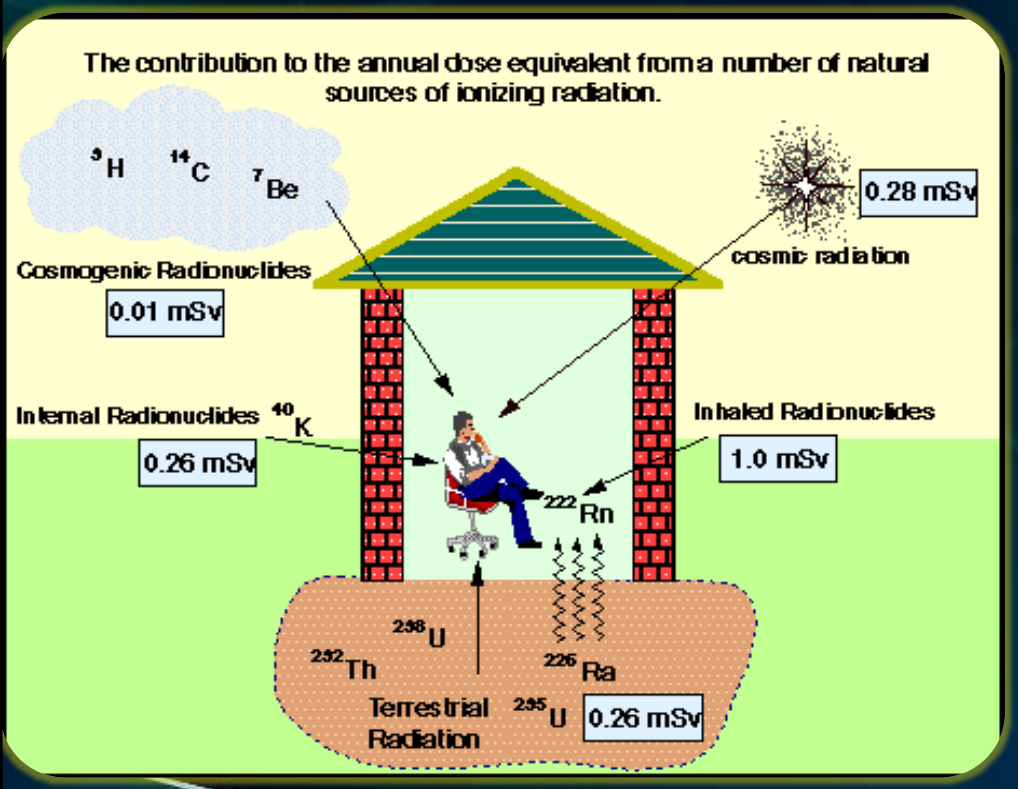
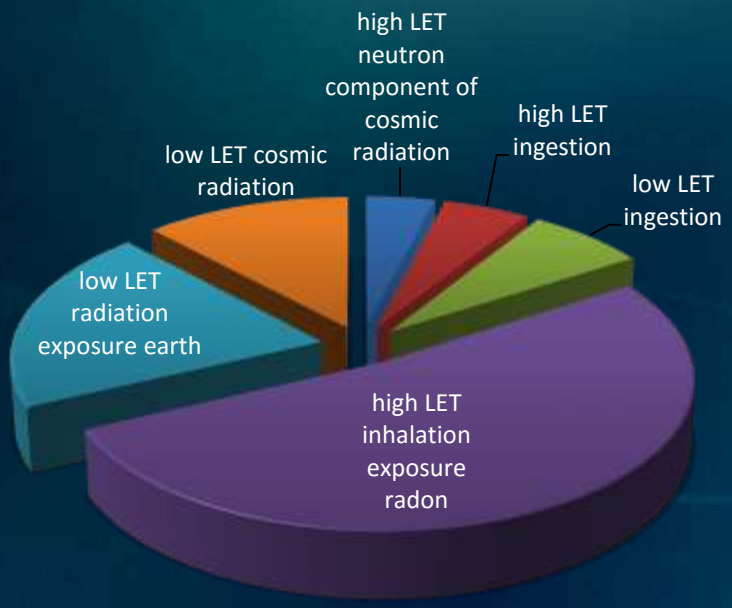
Background Radiation



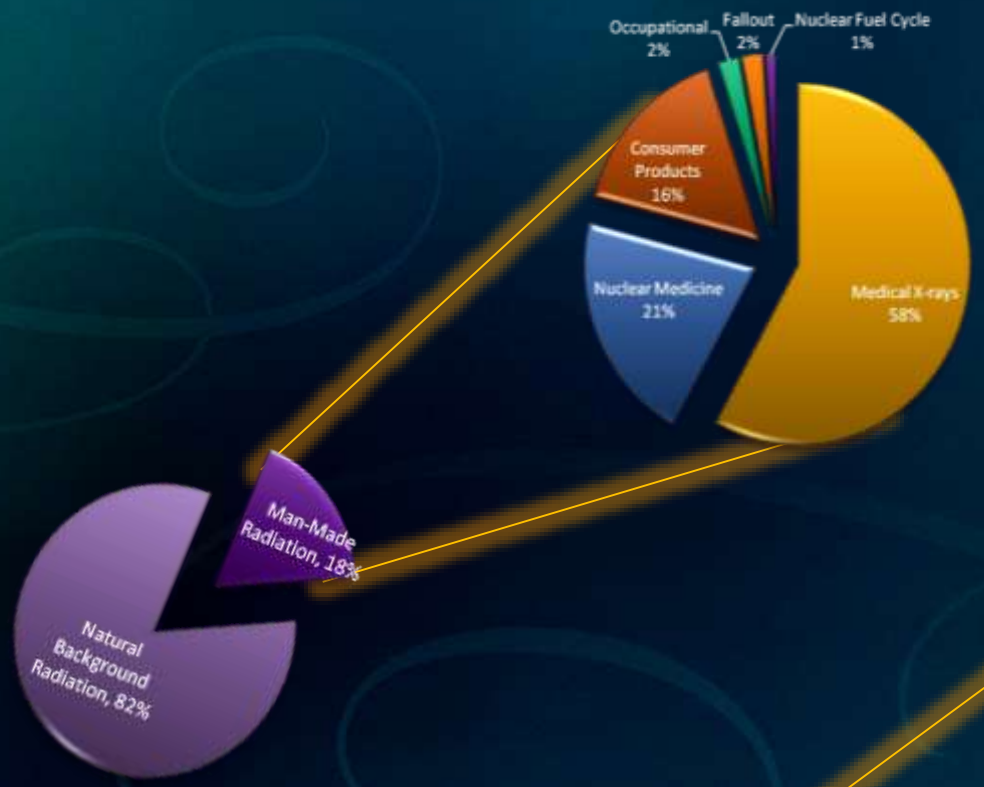


Some Exposure Limits

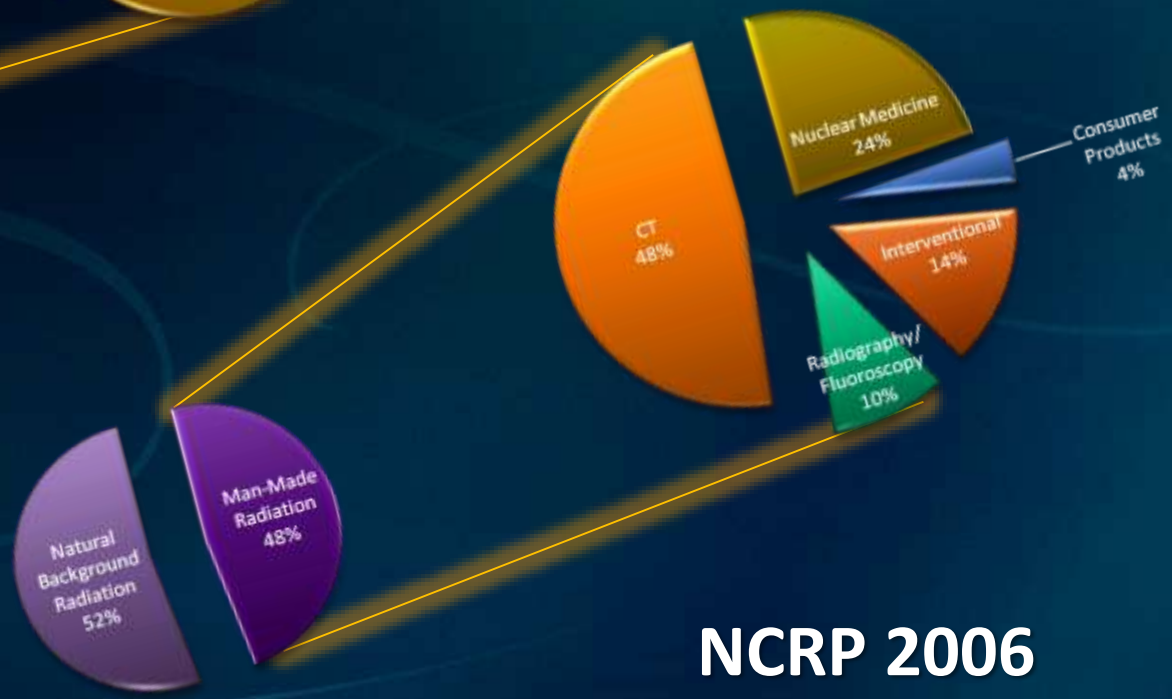
NRC Occupational Dose Limits

Whole Body (TEDE)	5,000 mrem/yr	= 50 mSv
Any Organ (TODE)	50,000 mrem/yr	= 500 mSv
Skin (SDE)	50,000 mrem/yr	= 500 mSv
Extremity (SDE)	50,000 mrem/yr	= 500 mSv
Lens of Eye (LDE)	15,000 mrem/yr	= 150 mSv
Embryo/Fetus of DPW	500 mrem/yr	= 5 mSv
Member of the Public	100 mrem/yr	= 1 mSv

Background Radiation

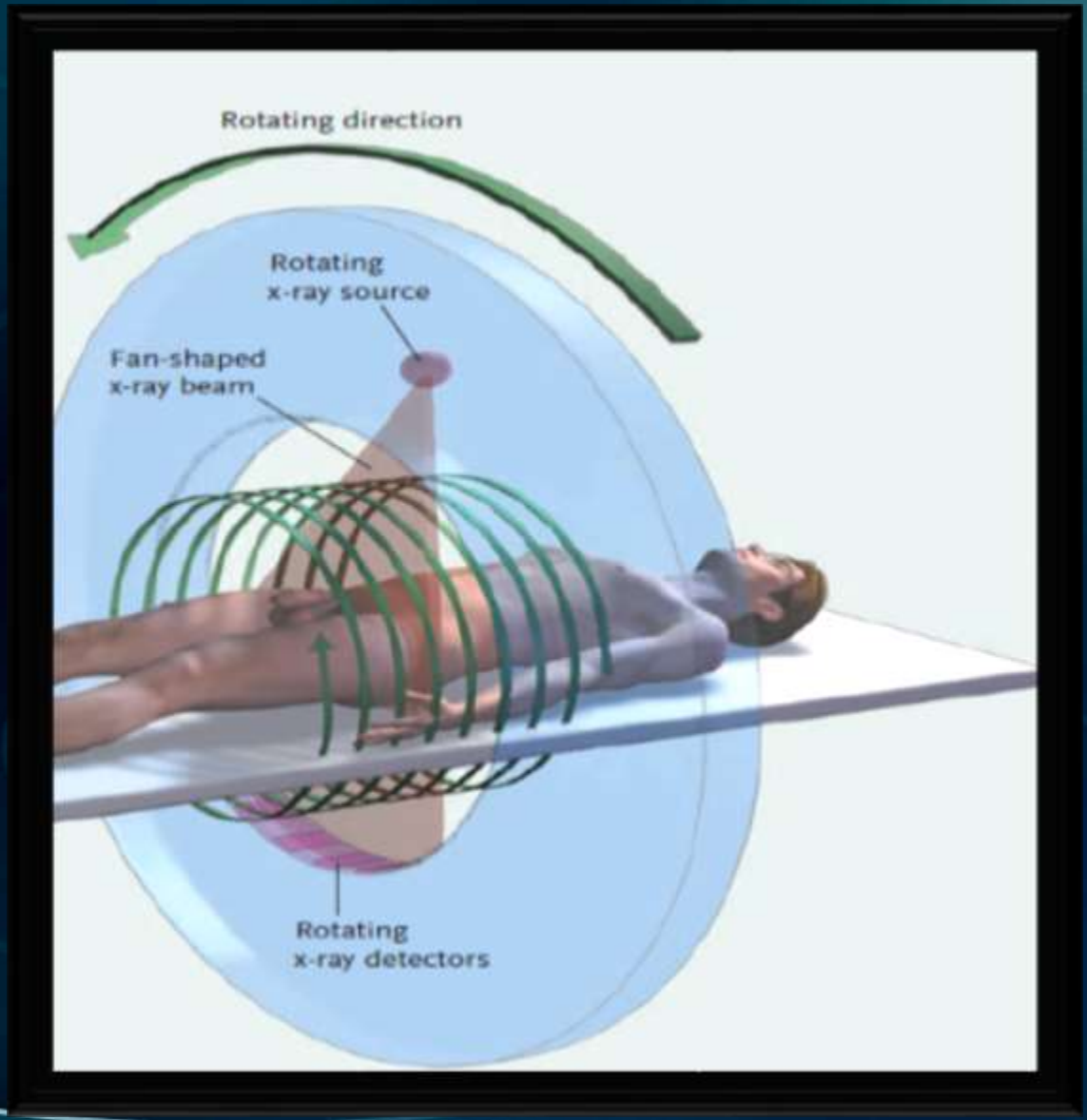


NCRP 1987



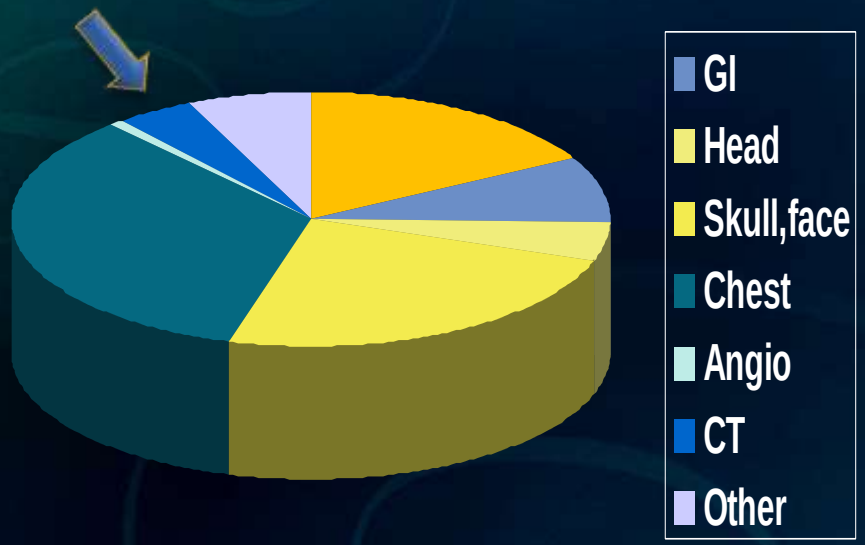
NCRP 2006

CT

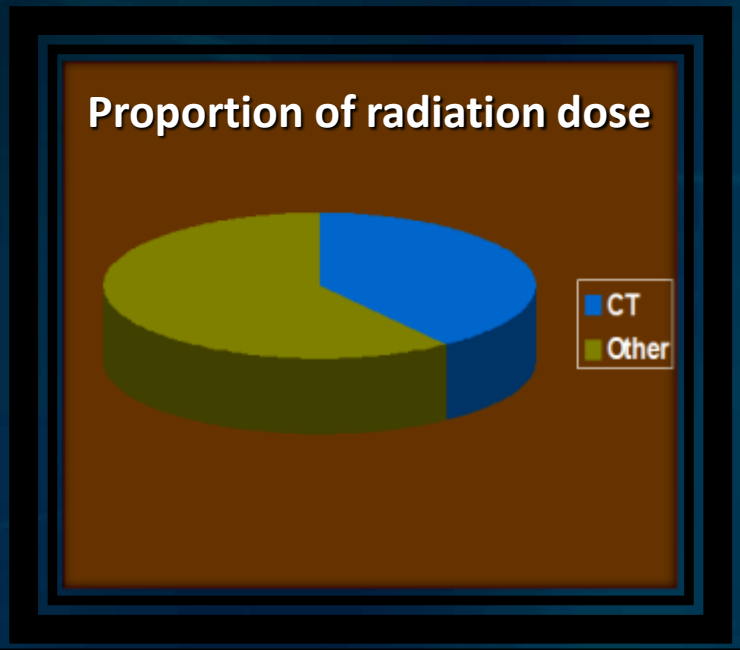

Rotating direction
Rotating
x-ray source
Fan-shaped
x-ray beam
Rotating
x-ray detectors

CT

Proportion of CT studies



- Approximately 30-40 x 10^6 CT examinations performed annually
- Approximately 5 – 11% of these are performed in children



From Frush DP. Pediatr Radiol 2002; 32:285

CT

Radiation Considerations

- Non-computerized radiography
  - Overexposure of film
  - overexposed technique
    - Melted radiographs
    - Diminished or lost diagnostic information

CT

Radiation Considerations

56 kvp @ 1.6 mas

56 kvp @ 2.0 mas

CT

Radiation Considerations

- Balance
  - Diagnostic needs
    - mAs ↑ SNR ↑
  - Radiation Exposure

CT Radiation Considerations

Helical CT of the Body: Are Settings Adjusted for Pediatric Patients?

Anne Paterson[1]
Donald P. Frush[2]
Lane F. Donnelly[3]

OBJECTIVE. Our objective was to determine whether adjustments related to patient age are made in the scanning parameters that are determinants of radiation dose for helical CT of pediatric patients.

SUBJECTS AND METHODS. This prospective investigation included all body (chest and abdomen) helical CT examinations ($n = 58$) of neonates, infants, and children ($n = 32$) referred from outside institutions for whom radiologic consultation was requested. Information recorded included tube current, kilovoltage, collimation, and pitch. Examinations were arbitrarily grouped on the basis of the individual's age: group A, 0–4 years; group B, 5–8 years; group C, 9–12 years; and group D, 13–16 years old.

RESULTS. Thirty-one percent (18/58) of the CT examinations were of the chest and 69% (40/58) were of the abdomen. Sixteen percent (9/58) of the CT examinations were combined chest and abdomen. In 22% (2/9) of these combined examinations, tube current was adjusted between the chest and abdomen CT; in one (11%) of these examinations, the tube current was higher for the chest than for the abdomen portion of the CT examination. The mean tube current setting for chest was 213 mA and was 206 mA for the abdomen, with no evident adjustment in tube current based on the age of the patient. Fifty-six percent of the examinations of neonates, infants, or children 8 years old or younger were performed at a collimation of greater than 5 mm and 53% of these examinations were performed using a pitch of 1.0.

CONCLUSION. Pediatric helical CT parameters are not adjusted on the basis of the examination type or the age of the child. In particular, these results suggest that pediatric patients may be exposed to an unnecessarily high radiation dose during body CT.

Helical CT is an important and increasingly used imaging technique in the pediatric population [1]. Although helical technology provides additional opportunities for CT in children, scanning techniques have become more sophisticated and complicated, and radiologists are faced with an expanding array of options, including the selection of scanning parameters [2]. These parameters include tube current, kilovoltage, collimation, and pitch. There is great variability in body size in the pediatric population, so adjustments of these parameters are necessary and important because these parameters are the main determinants of radiation dose received by the child. Although some technical recommendations are available for helical CT of children [1, 3–6], to the best of our knowledge, no information regarding adherence to these recommendations has been published.

There are several methods by which information about the common practice of helical CT techniques in pediatric patients can be obtained. One method is by a survey [7, 8]. Among the difficulties with this kind of sampling is assessing the validity of responses. We approached the issue of the practice of pediatric helical CT by another method in part to minimize this potential reporting bias. We collected and reviewed all chest and abdomen helical CT examinations in children 16 years old or younger performed at referring institutions or practices and submitted to our department for review. The objective of this type of survey was to determine what, if any, adjustments were made for CT examinations of children compared with adults and for CT examinations of pediatric patients of different ages. We focused on the adjustable scan parameters that primarily contribute to the amount of radiation the patient receives.

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0361–803X/01/1762–297

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Estimated Risks of Radiation-Induced Fatal Cancer from Pediatric CT

David J. Brenner[1]
Carl D. Elliston[1]
Eric J. Hall[1]
Walter E. Berdon[2]

OBJECTIVE. In light of the rapidly increasing frequency of pediatric CT examinations, the purpose of our study was to assess the lifetime cancer mortality risks attributable to radiation from pediatric CT.

MATERIALS AND METHODS. Organ doses as a function of age-at-diagnosis were estimated for common CT examinations, and estimated attributable lifetime cancer mortality risks (per unit dose) for different organ sites were applied. Standard models that assume a linear extrapolation of risks from intermediate to low doses were applied. On the basis of current standard practice, the same exposures (milliampere-seconds) were assumed, independent of age.

RESULTS. The larger doses and increased lifetime radiation risks in children produce a sharp increase, relative to adults, in estimated risk from CT. Estimated lifetime cancer mortality risks attributable to the radiation exposure from a CT in a 1-year-old are 0.18% (abdominal) and 0.07% (head)—an order of magnitude higher than for adults—although those figures still represent a small increase in cancer mortality over the natural background rate. In the United States, of approximately 600,000 abdominal and head CT examinations annually performed in children under the age of 15 years, a rough estimate is that 500 of these individuals might ultimately die from cancer attributable to the CT radiation.

CONCLUSION. The best available risk estimates suggest that pediatric CT will result in significantly increased lifetime radiation risk over adult CT, both because of the increased dose per milliampere-second, and the increased lifetime risk per unit dose. Lower milliampere-second settings can be used for children without significant loss of information. Although the risk–benefit balance is still strongly tilted toward benefit, because the frequency of pediatric CT examinations is rapidly increasing, estimates that quantitative lifetime radiation risks for children undergoing CT are not negligible may stimulate more active reduction of CT exposure settings in pediatric patients.

The use of CT has increased rapidly in the past two decades, fueled in part by the development of helical CT [1]. For example, the estimated annual number of CT examinations in the United States rose approximately sevenfold from 2.8 million in 1981 [2] to 20 million in 1995 [3]. By their nature, CT examinations contribute disproportionately to the collective diagnostic radiation dose to the population; for example, in Britain it has been estimated that approximately 4% of diagnostic radiology procedures are CT examinations, but their contribution to the collective dose is approximately 40% [4].

Figure 1 shows a breakdown of the number of CT examinations by age at examination, based on the results of a 1989 British survey [5]; in this survey, approximately 4% of CT examinations (which corresponds to about 10^6/year in the United States) were performed on children under the age of 15 years. The proportion of childhood CT examinations is rapidly increasing (indeed, an average value of 0% was estimated in 1993 [6]); for example, Coren et al. [7] reported a 63% increase in requests for pediatric CT between 1991 and 1994.

The recent increase in pediatric CT examinations is particularly marked in the United States. Figure 2 shows the number of abdominal and pelvic CT examinations of children under a given age at a major American children's hospital for 1996 through 1999. This figure shows, for example, a 92% increase between 1996 and 1999 in abdominal and pelvic CT examinations on children less

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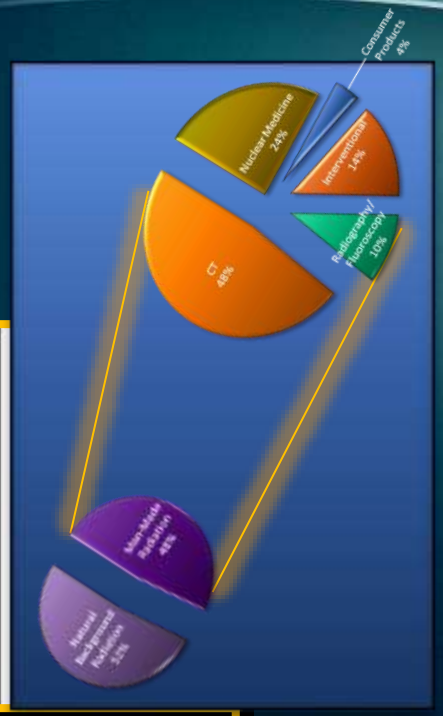
Life Span Study (LSS) – Japanese survivors

CT

Radiation Considerations



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LATE SPORTS

Super Bowl

Let the hype begin

Clock is ticking toward Sunday. Full report, 1-4C
▸ 10 years ago, war was on our minds, 1C
▸ Coming Friday: Bonus Section

USA TODAY

NO. 1 IN THE USA

'Gladiator' top film at Golden Globes

Julia Roberts takes best actress for *Erin Brockovich*; George Clooney gets comedy nod; Kate Hudson wins for *Almost Famous*. 1-2D
▸ The red carpet, 5D

Hudson: Best supporting actress.

Monday, January 22, 2001

Newsline

usatoday.com's new look

Get the latest news, stocks, scores and more right now at USA TODAY's 24-hour online news site, all with a clean new interface.

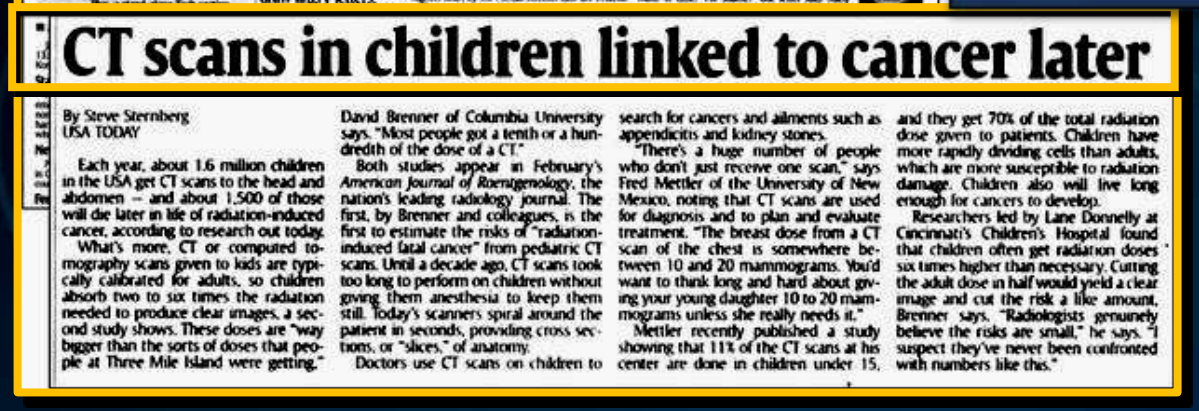
Election still splits court

Friction over justices' ruling on ballot count in Florida continues to cause hard feelings, draw angry letters.

By Joan Biskupic
USA TODAY

WASHINGTON — Six weeks after an uneasy U.S. Supreme Court cleared the way for Republican George W. Bush to become president, the scars left on the nation's highest court by the Florida election case are evident.

Meanwhile, the court has been bombarded with thousands of letters from angry Americans, some of whom have sent in their voter registration cards suggesting that going to the polls in November was a waste of time. "For shame!" one letter said. Many



CT scans in children linked to cancer later

By Steve Sternberg
USA TODAY

Each year, about 1.6 million children in the USA get CT scans to the head and abdomen — and about 1,500 of those will die later in life of radiation-induced cancer, according to research out today.

What's more, CT or computed tomography scans given to kids are typically calibrated for adults, so children absorb two to six times the radiation needed to produce clear images, a second study shows. These doses are "way bigger than the sorts of doses that people at Three Mile Island were getting," David Brenner of Columbia University says. "Most people got a tenth or a hundredth of the dose of a CT."

Both studies appear in February's *American Journal of Roentgenology*, the nation's leading radiology journal. The first, by Brenner and colleagues, is the first to estimate the risks of "radiation-induced fatal cancer" from pediatric CT scans. Until a decade ago, CT scans took too long to perform on children without giving them anesthesia to keep them still. Today's scanners spiral around the patient in seconds, providing cross sections, or "slices," of anatomy.

Doctors use CT scans on children to search for cancers and ailments such as appendicitis and kidney stones.

"There's a huge number of people who don't just receive one scan," says Fred Mettler of the University of New Mexico, noting that CT scans are used for diagnosis and to plan and evaluate treatment. "The breast dose from a CT scan of the chest is somewhere between 10 and 20 mammograms. You'd want to think long and hard about giving your young daughter 10 to 20 mammograms unless she really needs it."

Mettler recently published a study showing that 11% of the CT scans at his center are done in children under 15, and they get 70% of the total radiation dose given to patients. Children have more rapidly dividing cells than adults, which are more susceptible to radiation damage. Children also will live long enough for cancers to develop.

Researchers led by Lane Donnelly at Cincinnati's Children's Hospital found that children often get radiation doses six times higher than necessary. Cutting the adult dose in half would yield a clear image and cut the risk a like amount, Brenner says. "Radiologists genuinely believe the risks are small," he says. "I suspect they've never been confronted with numbers like this."

CT Radiation Considerations

- CTA Overdoses
- 8 hospitals; 3 in California
  - Cedars – Sinai Medical Ctr - Los Angeles
    - ≈ 269 patients
      - → Member of its Board of Governors
  - Providence Saint Joseph Medical Ctr – Burbank
    - ≈ 37 patients
  - Huntsville Hospital – Alabama
    - ≈ 65 patients

- Epilation, erythema

Lack of understanding of Automatic Exposure Control feature

CT Radiation Considerations

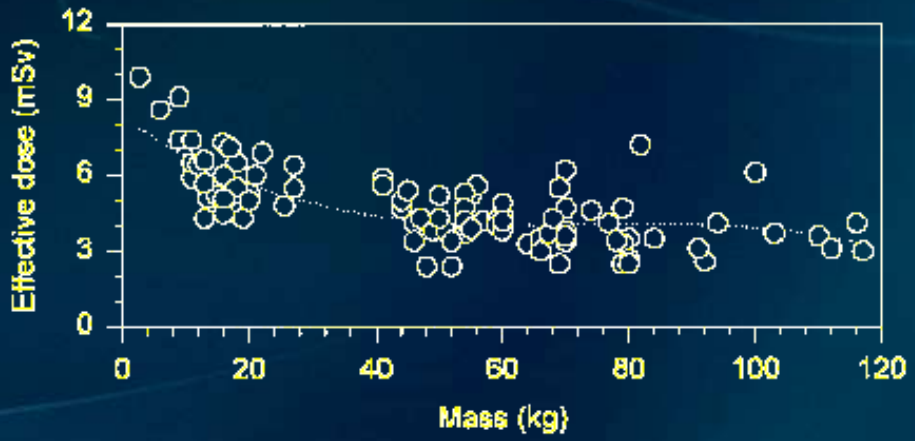
- 30 month old child
  - falls out of bed
- Mad River Community Hospital, Arcata CA
- CT scan is requested
  - activated 151 times over same area – 65 minutes
    - technologists denies fact, recalls only 4-6 times
  - study terminated by parent

Lack of understanding of equipment?

CT
Radiation Considerations

➢ The special case of Children

- Size
  - CT scanner dose calculated from 32cm phantom
  - For any given set of scanning parameters, effective dose will ↑ with ↓ cross-sectional area

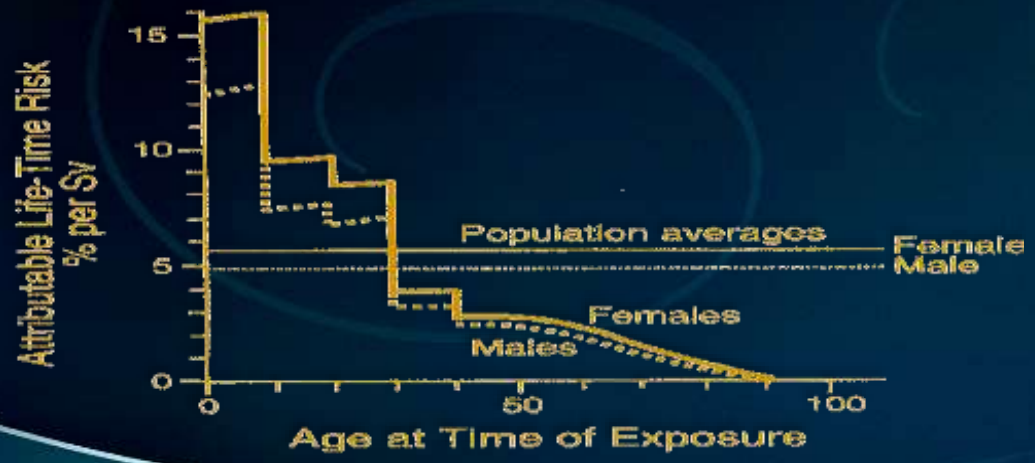


Ware et al Radiology 1999;210:640

CT
Radiation Considerations

The special case of Children

- Growing
  - Radiosensitive: M, G_1
  - Radioresistant: S
- Life-span
  - Latency periods
  - Cumulative doses



NCRP 1991 in Hall E 2002; 32:700

The Alliance for Radiation Safety in Pediatric Imaging

The *IMAGE GENTLY* campaign

The Alliance for Radiation Safety in Pediatric Imaging

- Coalition of health care organizations dedicated to providing safe, high quality pediatric imaging worldwide
- Primary objective is to raise awareness in the imaging community of the need to adjust radiation dose when imaging children
- Ultimate Goal

Change Practice

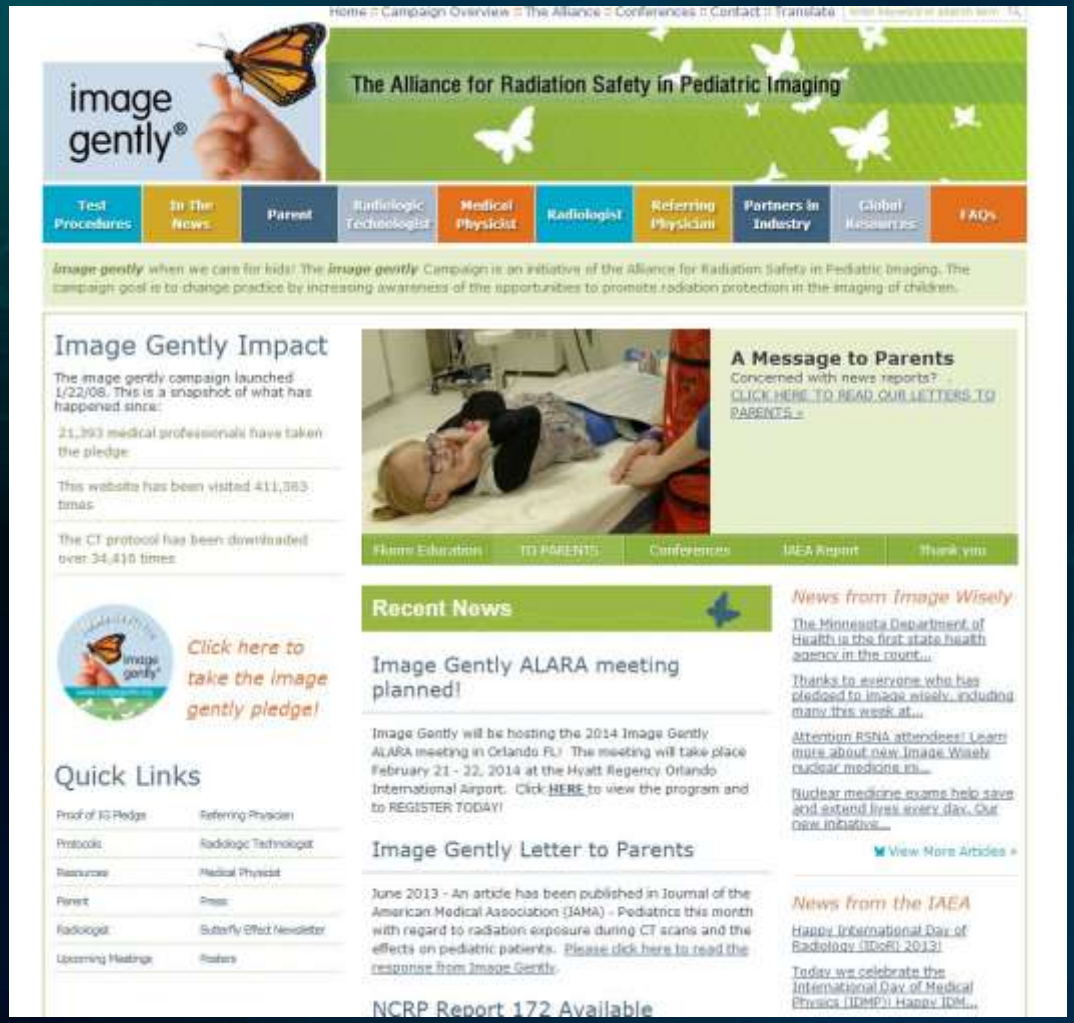
Image Gently - Background

- Society for Pediatric Radiology: 1400 members
  - Inaugural meeting September 29, 1958
  - First Radiology subspecialty society
- Mission statement
  - Professional organization dedicated to being the leader in advancing pediatric health care through medical imaging and image-related therapy
- Affiliated Societies
  - European Society for Pediatric Radiology
  - Asian and Oceanic Society for Paediatric Radiology
  - Sociedad Latinoamericana de Radiología Pediátrica

Image Gently - Background

- At RSNA, 2006 - meeting
  - Marilyn Goske President
  - George Taylor Board Chair
  - Marta Hernanz- Schulman President-elect
  - Jennifer Boylan Executive Director

The Alliance for Radiation Safety in Pediatric Imaging



- SPR
- ACR
- ASRT
- AAPM

> 74 OTHER SOCIETIES

www.imagegently.org

Image Gently - Background

- ***Alliance for Radiation Safety in Pediatric Imaging***
  - Writers' Meeting, Cincinnati July 23-24, 2007

    Hosted by Lane Donnelly
    - Creation/development of "imagegently.com" website
    - CT protocols development for sharing
    - Target content for audience levels: MESSAGE
    - KEEP IT SIMPLE
      - Image Gently: ***Jennifer Boylan***
      - "Let's be wise … adjust for size" ***Greg Morrison***

Campaign Roll-Out: to be January, 2008

The Alliance for Radiation Safety in Pediatric Imaging

- Children are more sensitive to radiation
- What we do now lasts their lifetime

So, when we image, let's image gently

More is often not better

When CT is the right thing to do

- Child-size kVp and mA
- One scan (single phase) is often enough
- Scan only the indicated areas

CT

Radiation Considerations

What can be done?

Image Gently

Image Wisely

Dose Optimization

CT
Radiation Considerations

Suggestions for mA settings in pediatric patients of various size

WEIGHT		mA	
LB	Kg	Chest	Abdomen
10 – 19	4.5 – 8.9	40	60
20 – 30	9 – 17.9	50	70
40 – 59	18 – 26.9	60	80
60 – 79	27 – 35.9	70	100
80 – 99	36 – 45	80	120
100 – 150	45.1 – 70	120-120	140 -150
> 150	> 70	> 140	> 170

Donnelly et al. AJR 2001;176:303

CT
Radiation Optimization

- Ensure that studies are indicated / affect management
  - Avoid multiphase examinations!
  - If needed, decrease technique as appropriate
  - Don't "try" a scan that may not work
  - Limit scan to area of interest
    - Don't scan testicles unnecessarily
    - Don't scan breasts unnecessarily
  - Alternative strategies (US, MR) when appropriate
- Child-size technique for pediatric and small patients
  - Image Gently website

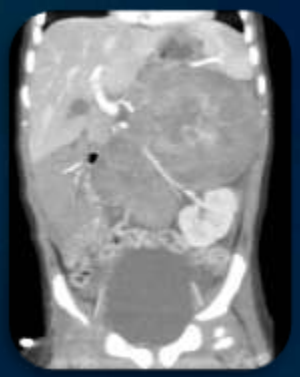
CT
Radiation Considerations

- Other parameters to consider
  - Table speed
    - Faster speed ⇒ faster scan
      - less radiation
      - less motion
  - Gantry rotation
    - Faster gantry rotation ⇒ faster scan
      - less radiation
      - less motion
  - CT angio
    - Lower kVp (100 medium- large patients, 80 small patients)

CT
Radiation Considerations

1997: 200mAs

2010: 70mAs



Fluoroscopy

Fluoroscopy

- Approximately 5,000 fluoroscopies annually
  - Maximum 17,000 (SCORCH survey, 2007)
- Dose regulations
  - "Normal mode": 10R/min exposure rate
  - "High dose": 20R/min (audible tone emitted)
  - "5 minute" reminder
    - ➢ No regulations on mode of operation, time, dose
      - → Privilege programs: training in radiation protection

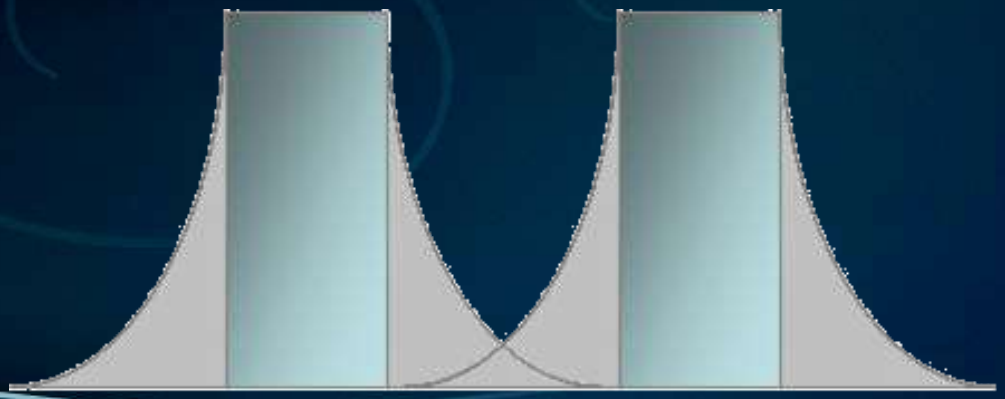
Pulsed fluoroscopy

RATIONALE:

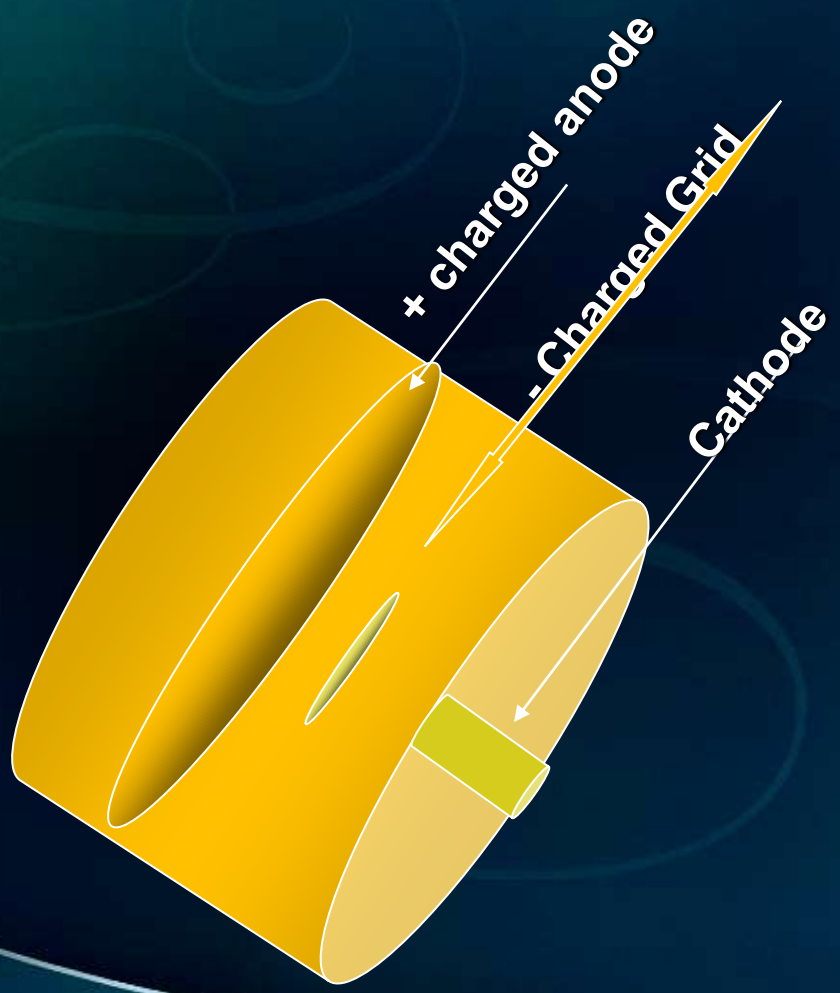
- Pulsing the X-ray will
  - decrease exposure time
  - decrease radiation dose

Pulsed fluoroscopy

- Voltage to the X-ray tube is switched on and off at the generator, at a given pulse rate: kVp pulsed fluoro
  - leads to a ramp-up and trail-down of the pulses
    - Based on the capacitance of the cable from generator to tube
  - Ramp-and-trail effect increases non-diagnostic radiation, without substantially reducing overall dose



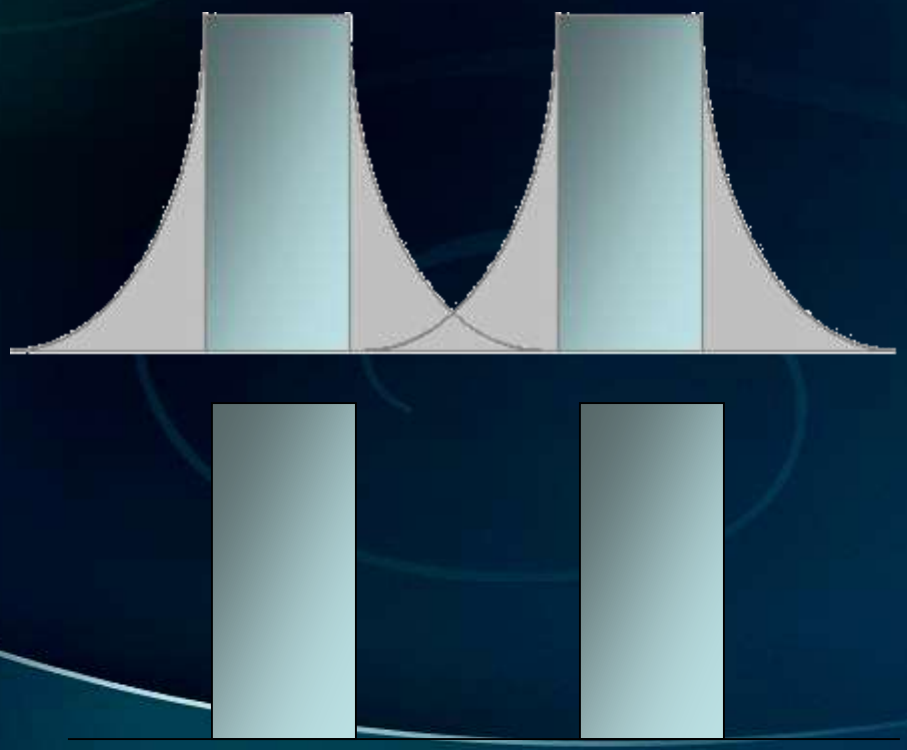
Grid-controlled fluoroscopy



- Negatively charged grid is interposed between cathode and anode
- Grid can be rapidly switched on and off, intermittently stopping the electron flow
- Results in true pulsed fluoroscopy

Grid-controlled fluoroscopy

- Grid-controlled fluoroscopy eliminates the ramp-and-trail effect
  - Diminished radiation dose
  - Sharper image



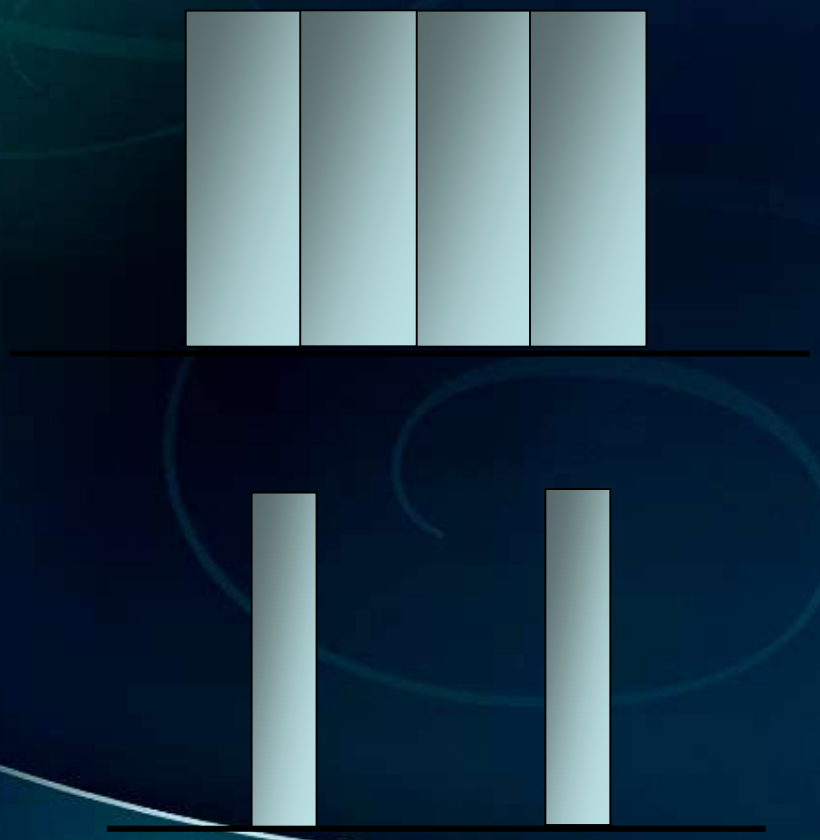
Grid-controlled fluoroscopy

Pulse Rate

- 30 pulses or frames per second is flicker-free to the human eye
- Continuous fluoroscopy is typically depicted at 30 frames per second

Grid-controlled fluoroscopy

What is the difference ?



- Continuous fluoroscopy
- 30 pulses per second
- 33 msec pulse width

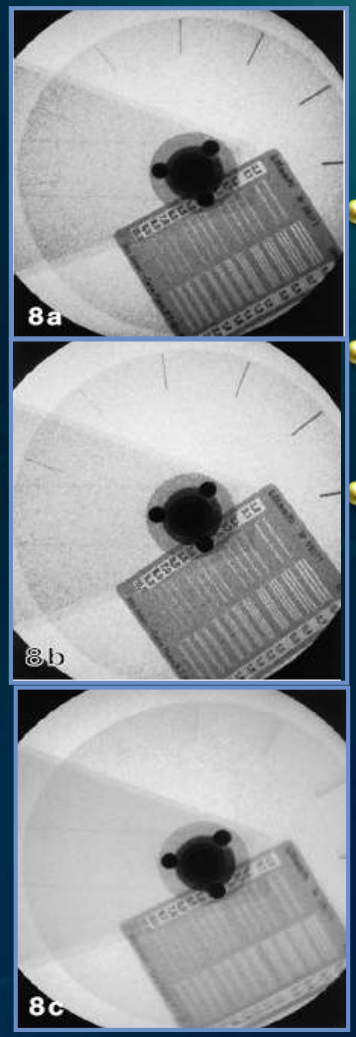
- Grid-controlled fluoroscopy (e.g.)
  - e.g. 15 pulses / sec
  - 20 msec pulse width

Grid-controlled fluoroscopy

- Effect on moving objects
  - Continuous fluoroscopy
    - blurring of rapidly moving objects
      - function of longer pulse width
  - Pulsed fluoroscopy
    - flicker effect
      - pulse rates < 15/sec

Grid-controlled fluoroscopy

- What is the effect on image quality?
  - 2 p/sec
  - 8 p/sec
  - continuous

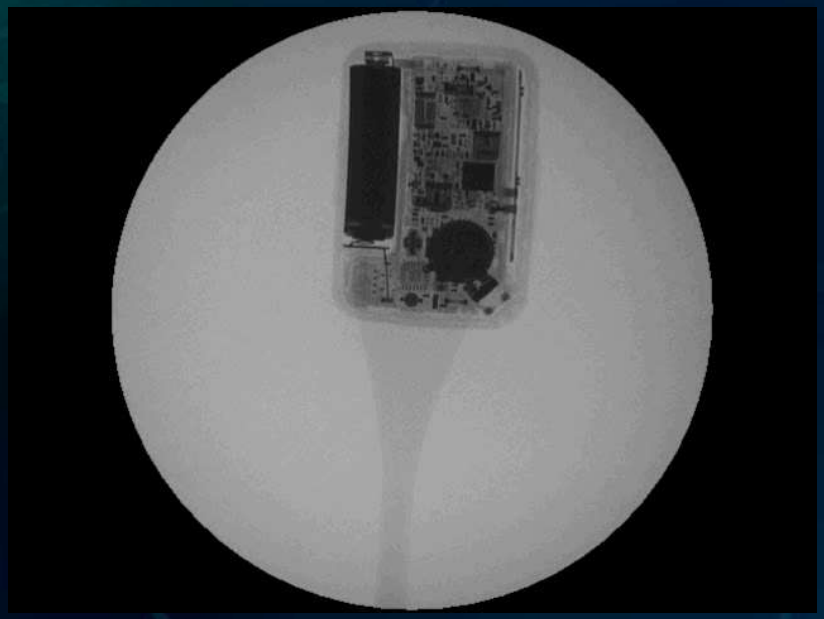


- Moving phantom
- 1rev/8 sec
- 2cm/sec at circumference

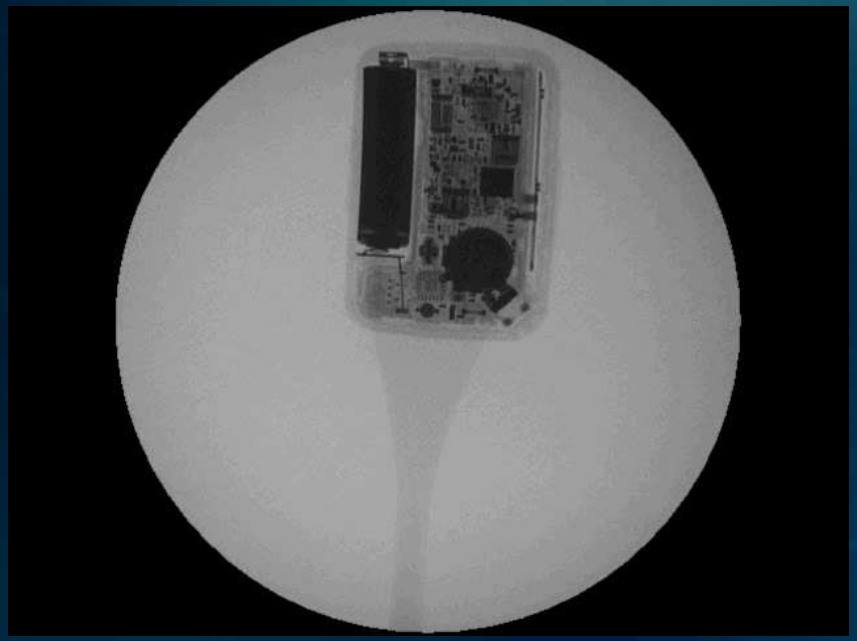
✓**33% more moving objects seen with pulsed than with continuous fluoroscopy**

Brown et al. Pediatr Radiol 2000;30:236

Grid-controlled fluoroscopy



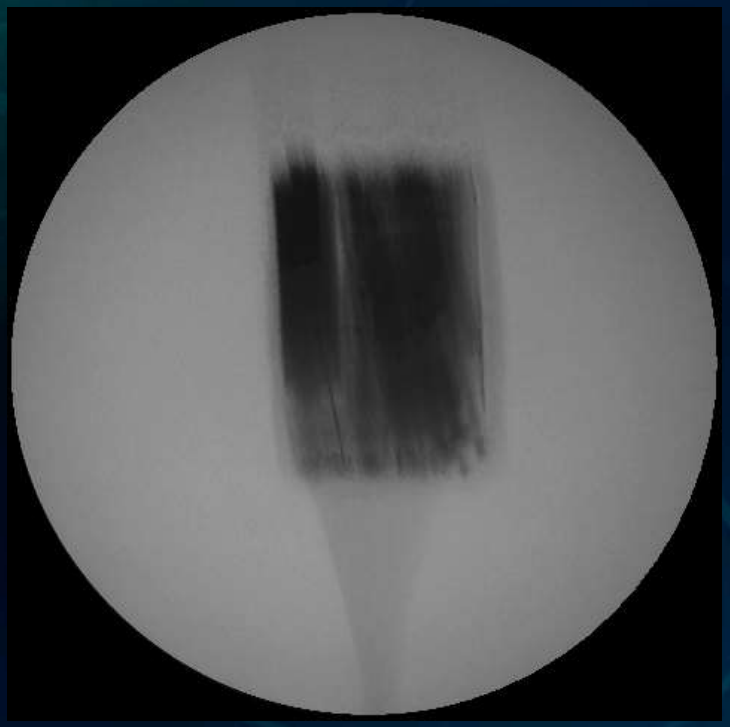
Continuous fluoroscopy

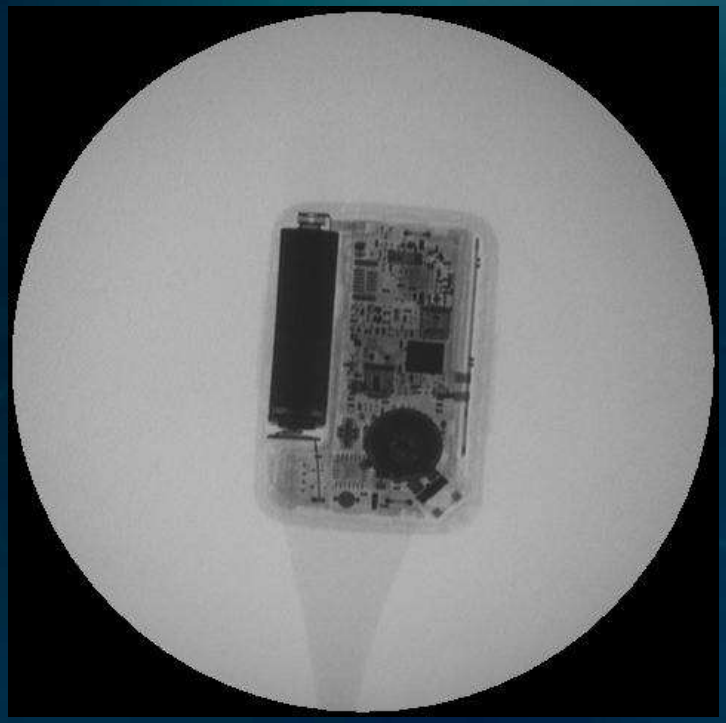


15 pulses per second

Grid-controlled fluoroscopy

Frame during motion

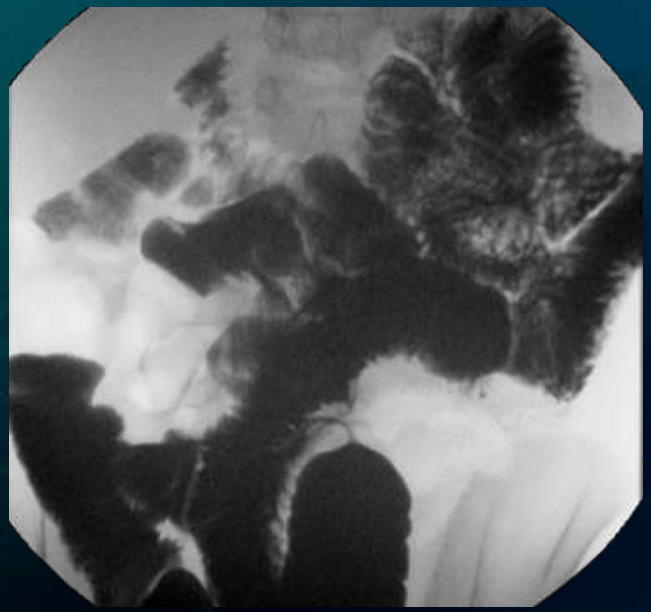




Continuous fluoroscopy

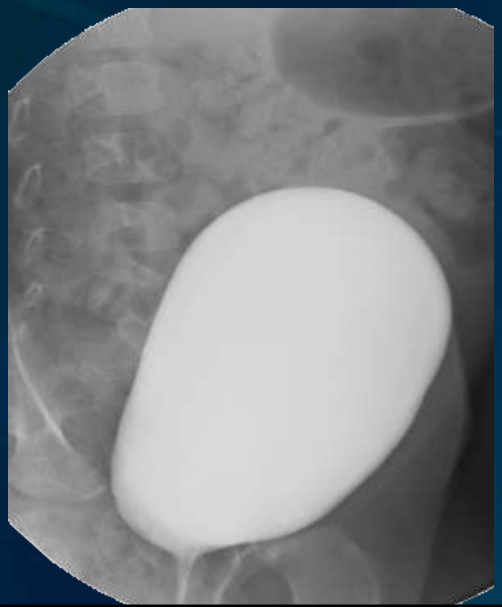
15 pps

Still images: exposure vs grab



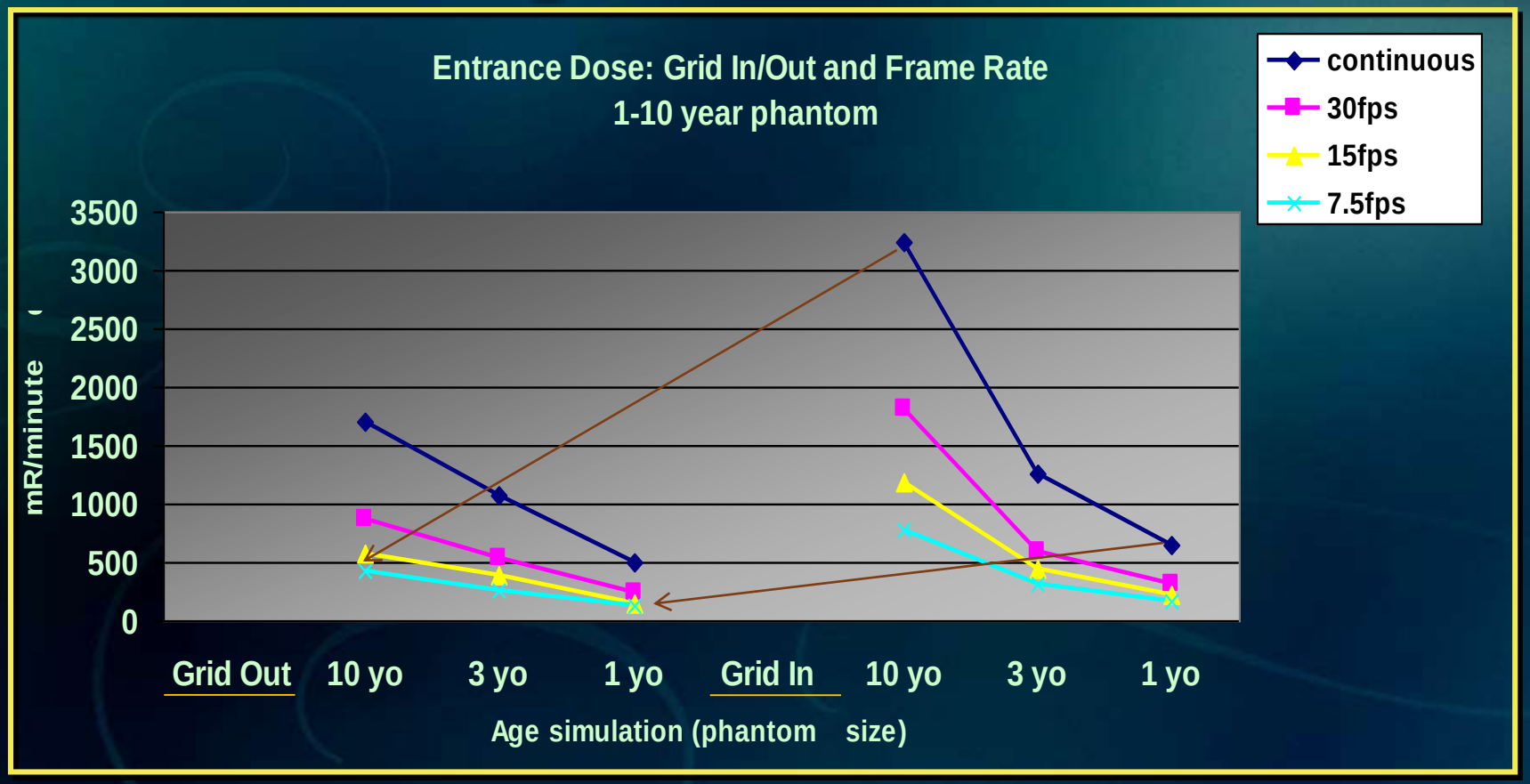
Fluoro-grab

Exposure



Fluoro – Grab: “moving” images

Anti-scatter grid: dose



- 7.5pps no grid vs. continuous with grid
  - 1 year old: 649/126 = 80% reduction
  - 10 year old: 3,250/425 = 87% reduction

Where are we today?

The Alliance for Radiation Safety in Pediatric Imaging

- Interventional Radiology

Step Lightly

- Fluoroscopy

Pause & Pulse

- CR-DR

BACK TO BASICS

- Nuclear Medicine

GO WITH THE GUIDELINES

CT
Radiation Considerations

The New York Times

We Are Giving Ourselves Cancer
By RITA F. REDBERG and REBECCA SMITH-BINDMAN JAN. 30, 2014

The radiation doses of CT scans (a series of X-ray images from multiple angles) are 100 to 1,000 times higher than conventional X-rays.

CT Radiation Considerations

The NEW ENGLAND JOURNAL of MEDICINE

REVIEW ARTICLE

CURRENT CONCEPTS

Computed Tomography — An Increasing Source of Radiation Exposure

David J. Brenner, Ph.D., D.Sc., and Eric J. Hall, D.Phil., D.Sc.

THE ADVENT OF COMPUTED TOMOGRAPHY (CT) HAS REVOLUTIONIZED Diagnostic radiology. Since the inception of CT in the 1970s, its use has increased rapidly. It is estimated that more than 62 million CT scans per year are currently obtained in the United States, including at least 4 million for children.[1]

By its nature, CT involves larger radiation doses than the more common, conventional x-ray imaging procedures (Table 1). We briefly review the nature of CT scanning and its main clinical applications, both in symptomatic patients and in a more recent development, in the screening of asymptomatic patients. We focus on the increasing number of CT scans being obtained, the associated radiation doses, and the consequent cancer risks in adults and particularly in children. Although the risks for any one person are not large, the increased exposure to radiation in the population may be a public health issue in the future.

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N Engl J Med 2007;357:2277-84.

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CT AND ITS USE

The basic principles of axial and helical (also known as spiral) CT scanning are illustrated in Figure 1. CT has transformed much of medical imaging by providing three-dimensional views of the human body region of interest.

The use of CT has increased rapidly in the United States and elsewhere, notably in Japan; according to a survey conducted in 1996,[2] the number of CT scanners per 1 million population was 26 in the United States and 64 in Japan. It is estimated that more than 62 million CT scans are currently obtained each year in the United States, as compared with about 3 million in 1980 (Fig. 2).[3] This sharp increase has been driven largely by advances in CT technology that make it extremely user-friendly, for both the patient and the physician.

COMMON TYPES OF CT SCANS

CT use can be categorized according to the population of patients (adult or pediatric) and the purpose of imaging (diagnosis in symptomatic patients or screening of asymptomatic patients). CT-based diagnosis in adults is the largest of these categories. (About half of diagnostic CT examinations in adults are scans of the body, and about one third are scans of the head, with about 75% obtained in a hospital setting and 25% in a single-specialty practice setting.[4]) The largest increases in CT use, however, have been in the categories of pediatric diagnosis[4,5] and adult screening,[6-13] and these trends can be expected to continue for the next few years.

The growth of CT use in children has been driven primarily by the decrease in the time needed to perform a scan — now less than 1 second — largely eliminating the need for anesthesia to prevent the child from moving during image ac-

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> 4000 citations

Estimated Risks of Radiation-Induced Fatal Cancer from Pediatric CT

David J. Brenner[1]
Carl D. Elliston[1]
Eric J. Hall[1]
Walter E. Berdon[2]

OBJECTIVE. In light of the rapidly increasing frequency of pediatric CT examinations, the purpose of our study was to assess the lifetime cancer mortality risks attributable to radiation from pediatric CT.

MATERIALS AND METHODS. Organ doses as a function of age-at-diagnosis were estimated for common CT examinations, and estimated attributable lifetime cancer mortality risks (per unit dose) for different organ sites were applied. Standard models that assume a linear extrapolation of risks from intermediate to low doses were applied. On the basis of current standard practice, the same exposures (milliampere-seconds) were assumed, independent of age.

RESULTS. The larger doses and increased lifetime radiation risks in children produce a sharp increase, relative to adults, in estimated risk from CT. Estimated lifetime cancer mortality risks attributable to the radiation exposure from a CT in a 1-year-old are 0.18% (abdominal) and 0.07% (head)—an order of magnitude higher than for adults—although those figures still represent a small increase in cancer mortality over the natural background rate. In the United States, of approximately 600,000 abdominal and head CT examinations annually performed in children under the age of 15 years, a rough estimate is that 500 of these individuals might ultimately die from cancer attributable to the CT radiation.

CONCLUSION. The best available risk estimates suggest that pediatric CT will result in significantly increased lifetime radiation risk over adult CT, both because of the increased dose per milliampere-second, and the increased lifetime risk per unit dose. Lower milliampere-second settings can be used for children without significant loss of information. Although the risk–benefit balance is still strongly tilted toward benefit, because the frequency of pediatric CT examinations is rapidly increasing, estimates that quantitative lifetime radiation risks for children undergoing CT are not negligible may stimulate more active reduction of CT exposure settings in pediatric patients.

The use of CT has increased rapidly in the past two decades, fueled in part by the development of helical CT [1]. For example, the estimated annual number of CT examinations in the United States rose approximately sevenfold from 2.8 million in 1981 [2] to 20 million in 1995 [3]. By their nature, CT examinations contribute disproportionately to the collective diagnostic radiation dose to the population; for example, in Britain it has been estimated that approximately 4% of diagnostic radiology procedures are CT examinations, but their contribution to the collective dose is approximately 40% [4].

Figure 1 shows a breakdown of the number of CT examinations by age at examination, based on the results of a 1989 British survey [5]; in this survey, approximately 4% of CT examinations (which corresponds to about 10^6/year in the United States) were performed on children under the age of 15 years. The proportion of childhood CT examinations is rapidly increasing (indeed, an average value of 0% was estimated in 1993 [6]); for example, Coren et al. [7] reported a 63% increase in requests for pediatric CT between 1991 and 1994.

The recent increase in pediatric CT examinations is particularly marked in the United States. Figure 2 shows the number of abdominal and pelvic CT examinations of children under a given age at a major American children's hospital for 1996 through 1999. This figure shows, for example, a 92% increase between 1996 and 1999 in abdominal and pelvic CT examinations on children less

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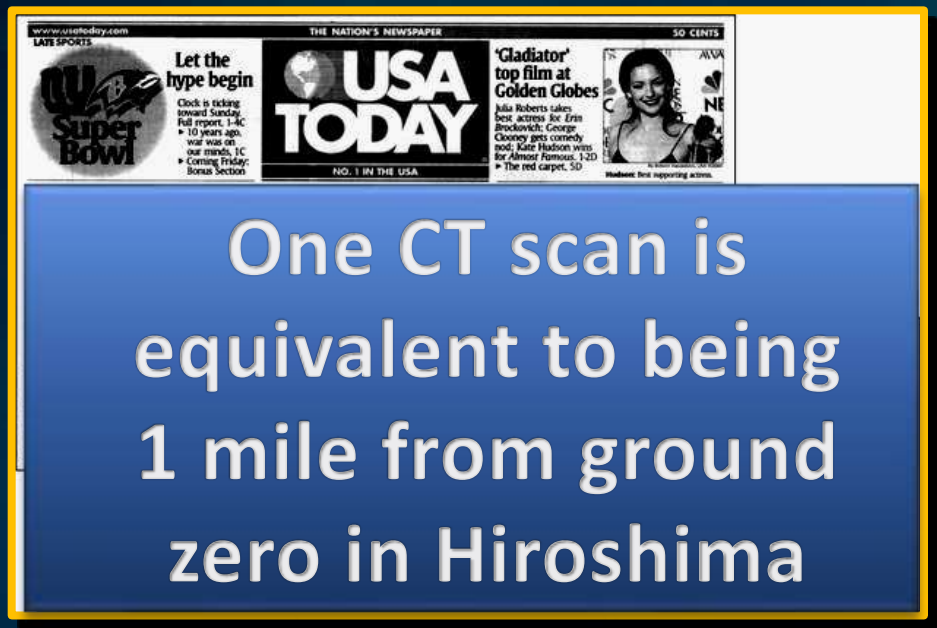
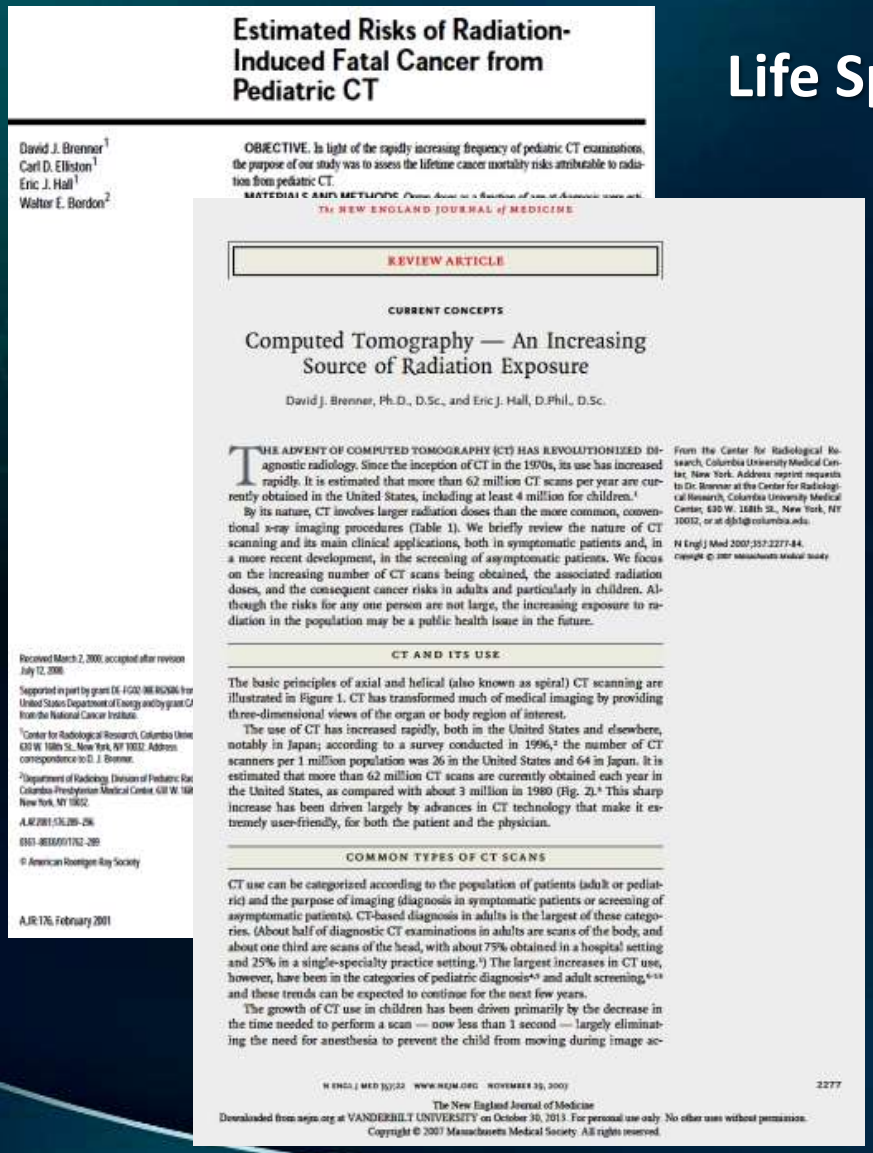


One CT scan is equivalent to being 1 mile from ground zero in Hiroshima

Life Span Study (LSS) – Japanese survivors

CT



Estimated Risks of Radiation-Induced Fatal Cancer from Pediatric CT

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OBJECTIVE. In light of the rapidly increasing frequency of pediatric CT examinations, the purpose of our study was to assess the lifetime cancer mortality risks attributable to radiation from pediatric CT.

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The NEW ENGLAND JOURNAL of MEDICINE

REVIEW ARTICLE

CURRENT CONCEPTS

Computed Tomography — An Increasing Source of Radiation Exposure

David J. Brenner, Ph.D., D.Sc., and Eric J. Hall, D.Phil., D.Sc.

THE ADVENT OF COMPUTED TOMOGRAPHY (CT) HAS REVOLUTIONIZED DIagnostic radiology. Since the inception of CT in the 1970s, its use has increased rapidly. It is estimated that more than 62 million CT scans per year are currently obtained in the United States, including at least 4 million for children.[1]

By its nature, CT involves larger radiation doses than the more common, conventional x-ray imaging procedures (Table 1). We briefly review the nature of CT scanning and its main clinical applications, both in symptomatic patients and, in a more recent development, in the screening of asymptomatic patients. We focus on the increasing number of CT scans being obtained, the associated radiation doses, and the consequent cancer risks in adults and particularly in children. Although the risks for any one person are not large, the increasing exposure to radiation in the population may be a public health issue in the future.

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CT AND ITS USE

The basic principles of axial and helical (also known as spiral) CT scanning are illustrated in Figure 1. CT has transformed much of medical imaging by providing three-dimensional views of the organ or body region of interest.

The use of CT has increased rapidly, both in the United States and elsewhere, notably in Japan; according to a survey conducted in 1996,[2] the number of CT scanners per 1 million population was 26 in the United States and 64 in Japan. It is estimated that more than 62 million CT scans are currently obtained each year in the United States, as compared with about 3 million in 1980 (Fig. 2).[3] This sharp increase has been driven largely by advances in CT technology that make it extremely user-friendly, for both the patient and the physician.

COMMON TYPES OF CT SCANS

CT use can be categorized according to the population of patients (adult or pediatric) and the purpose of imaging (diagnosis in symptomatic patients or screening of asymptomatic patients). CT-based diagnosis in adults is the largest of these categories. (About half of diagnostic CT examinations in adults are scans of the body, and about one third are scans of the head, with about 75% obtained in a hospital setting and 25% in a single-specialty practice setting.[1]) The largest increases in CT use, however, have been in the categories of pediatric diagnosis[4,5] and adult screening,[6-13] and these trends can be expected to continue for the next few years.

The growth of CT use in children has been driven primarily by the decrease in the time needed to perform a scan — now less than 1 second — largely eliminating the need for anesthesia to prevent the child from moving during image ac-

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Life Span Study (LSS) – Japanese survivors

- Whole body radiation
- Subject to recall
  - $1/d^2$
- α, β and neutrons
  - water and food supply

CT

"Dose estimates are subject to uncertainty, especially that due to survivor location and shielding.
The cohort provides no information on dose-rate effects since all exposure is at high dose rates.
Although estimates based only on survivors with lower doses can be made, their statistical uncertainty is considerably greater than those that include survivors with higher doses."

BEIR VII Phase 2, (2006) Biological Effects of Ionizing Radiation

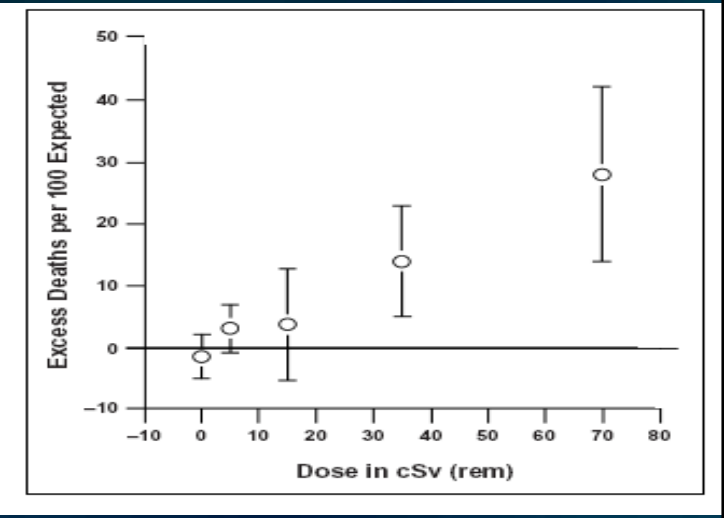


Fig. 1.—Plot shows number of deaths from solid tumors per 100 in excess of expected deaths among Japanese atomic bomb survivors (1950–1990) versus their dose. Error bars show 95% confidence limits.

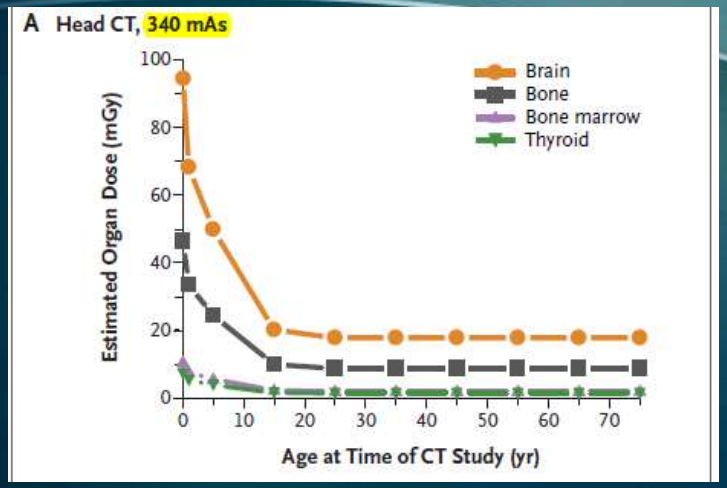
Cohen B. Cancer Risk from low-level radiation AJR 2002; 179:1137-1143

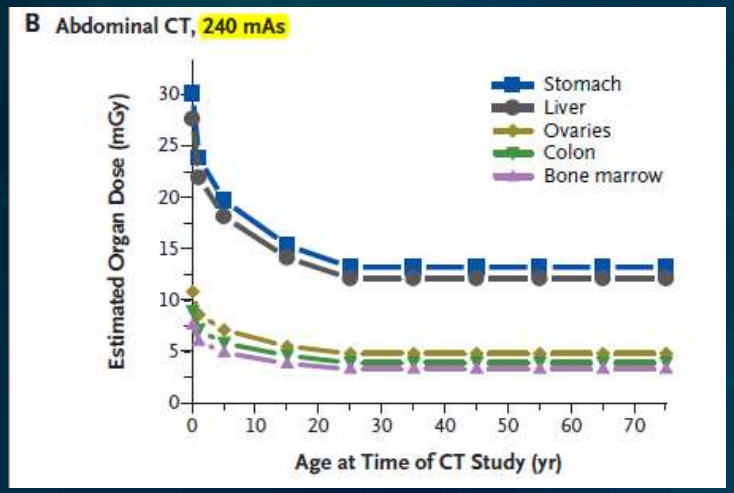
CT Radiation Considerations

- Effective doses
  - neonates body CT : 2.5 mSev
  - neonates head CT: 3.6 mSev

TABLE 3: Patient Age- and Weight-Specific CT Protocols (120 kV) Used to Determine Representative Patient Organ and Effective Doses

Patient		Head (Axial or Contiguous)		Chest (Pitch = 1.5)		Abdomen (Pitch = 1.5)	
Age	Weight (kg)	mAs	Scan Length (cm)	mAs	Scan Length (cm)	mAs	Scan Length (cm)
Newborn	3.5	160	11	40	10	50	6
6 mo	7.5	170	11	45	14	60	8
1 y	9.9	180	11	45	15	60	9
2 y	12.3	200	11	50	18	70	10
5 y	18.5	230	12	55	22	75	13
10 y	32.5	260	12	80	28	100	16
15 y	54	280	12	120	34	140	20
Adult	70	300	13	170	35	190	20
Oversized adult	120	300	13	300	35	350	20





Huda W, Vance A. Patient radiation doses from adult and pediatric CT. AJR 2007;188:540-546

Values cited by Brenner & Hall

> 10X higher than used in pediatric institutions

CT
Radiation Considerations

Radiation exposure from CT scans in childhood and subsequent risk of leukaemia and brain tumours: a retrospective cohort study

Summary

Background Although CT scans are very useful clinically, potential cancer risks exist from associated ionising radiation, in particular for children who are more radiosensitive than adults. We aimed to assess the excess risk of leukaemia and brain tumours after CT scans in a cohort of children and young adults.

Methods In our retrospective cohort study, we included patients without previous cancer diagnoses who were first examined with CT in National Health Service (NHS) centres in England, Wales, or Scotland (Great Britain) between 1985 and 2002, when they were younger than 22 years of age. We obtained data for cancer incidence, mortality, and loss to follow-up from the NHS Central Registry from Jan 1, 1985, to Dec 31, 2008. We estimated absorbed brain and red bone marrow doses per CT scan in mGy and assessed excess incidence of leukaemia and brain tumours cancer with Poisson relative risk models. To avoid inclusion of CT scans related to cancer diagnosis, follow-up for leukaemia began 2 years after the first CT and for brain tumours 5 years after the first CT.

Findings During follow-up, 74 of 178 604 patients were diagnosed with leukaemia and 135 of 176 587 patients were diagnosed with brain tumours. We noted a positive association between radiation dose from CT scans and leukaemia (excess relative risk [ERR] per mGy 0·036, 95% CI 0·005–0·120; p=0·0097) and brain tumours (0·023, 0·010–0·049; p<0·0001). Compared with patients who received a dose of less than 5 mGy, the relative risk of leukaemia for patients who received a cumulative dose of at least 30 mGy (mean dose 51·13 mGy) was 3·18 (95% CI 1·46–6·94) and the relative risk of brain cancer for patients who received a cumulative dose of 50–74 mGy (mean dose 60·42 mGy) was 2·82 (1·33–6·03).

Interpretation Use of CT scans in children to deliver cumulative doses of about 50 mGy might almost triple the risk of leukaemia and doses of about 60 mGy might triple the risk of brain cancer. Because these cancers are relatively rare, the cumulative absolute risks are small: in the 10 years after the first scan for patients younger than 10 years, one excess case of leukaemia and one excess case of brain tumour per 10 000 head CT scans is estimated to occur. Nevertheless, although clinical benefits should outweigh the small absolute risks, radiation doses from CT scans ought to be kept as low as possible and alternative procedures, which do not involve ionising radiation, should be considered if appropriate.

Funding US National Cancer Institute and UK Department of Health.

Introduction

CT imaging is a valuable diagnostic technique, and new clinical applications continue to be identified. As a result, ...

Methods

Patients and study design

BMJ

BMJ 2013;346:f2360 doi: 10.1136/bmj.f2360 (Published 21 May 2013)

RESEARCH

Cancer risk in 680 000 people exposed to computed tomography scans in childhood or adolescence: data linkage study of 11 million Australians

OPEN ACCESS

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Abstract

Objective To assess the cancer risk in children and adolescents following exposure to low dose ionising radiation from diagnostic computed tomography (CT) scans.

Design Population based, cohort, data linkage study in Australia.

Cohort members 10.9 million people identified from Australian Medicare records, aged 0-19 years on 1 January 1985 or born between 1 January 1985 and 31 December 2005; all exposures to CT scans funded by Medicare during 1985-2005 were identified for this cohort. Cancers diagnosed in cohort members up to 31 December 2007 were obtained through linkage to national cancer records.

Main outcome Cancer incidence rates in individuals exposed to a CT scan more than one year before any cancer diagnosis, compared with cancer incidence rates in unexposed individuals.

Results 60 674 cancers were recorded, including 3150 in 680 211 people exposed to a CT scan at least one year before any cancer diagnosis. The mean duration of follow-up after exposure was 9.5 years. Overall cancer incidence was 24% greater for exposed than for unexposed people, after accounting for age, sex, and year of birth (incidence rate ratio (IRR) 1.24 (95% confidence interval 1.20 to 1.29); P<0.001). We saw a dose-response relation, and the IRR increased by 0.16 (0.13 to 0.19) for each additional CT scan. The IRR was greater after exposure at younger ages (P<0.001 for trend). At 1-4, 5-9, 10-14, and 15 or more years since first exposure, IRRs were 1.35 (1.25 to 1.45), 1.25 (1.17 to 1.34), 1.14 (1.06 to 1.22), and 1.24 (1.14 to 1.34), respectively. The IRR increased significantly for many types of solid cancer (digestive organs, melanoma, soft tissue, female genital, urinary tract, brain, and thyroid); leukaemia, myelodysplasia, and some other lymphoid cancers. There was an excess of 608 cancers in people exposed to CT scans (147 brain, 356 other solid, 48 leukaemia or myelodysplasia, and 57 other lymphoid). The absolute excess incidence rate for all cancers combined was 9.38 per 100 000 person years at risk, as of 31 December 2007. The average effective radiation dose per scan was estimated as 4.5 mSv.

Conclusions The increased incidence of cancer after CT scan exposure in this cohort was mostly due to irradiation. Because the cancer excess was still continuing at the end of follow-up, the eventual lifetime risk from CT scans cannot yet be determined. Radiation doses from contemporary CT scans are likely to be lower than those in 1985-2005, but some increase in cancer risk is still likely from current scans. Future CT scans should be limited to situations where there is a definite clinical indication, with every scan optimised to provide a diagnostic CT image at the lowest possible radiation dose.

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Extra material supplied by the author (see http://www.bmj.com/content/346/bmj.f2360?tab=related#webextra)

Web appendix: Supplementary material

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CT

- Retrospective studies of very large cohorts

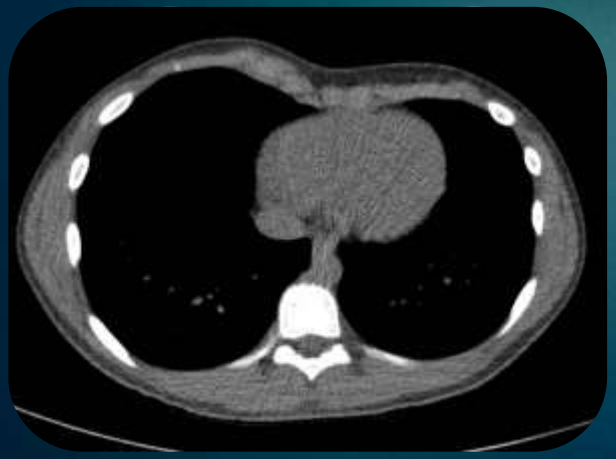
- Reason for studies
  - Reverse causation?
- Radiation dose used, multiphase, repeats - unknown

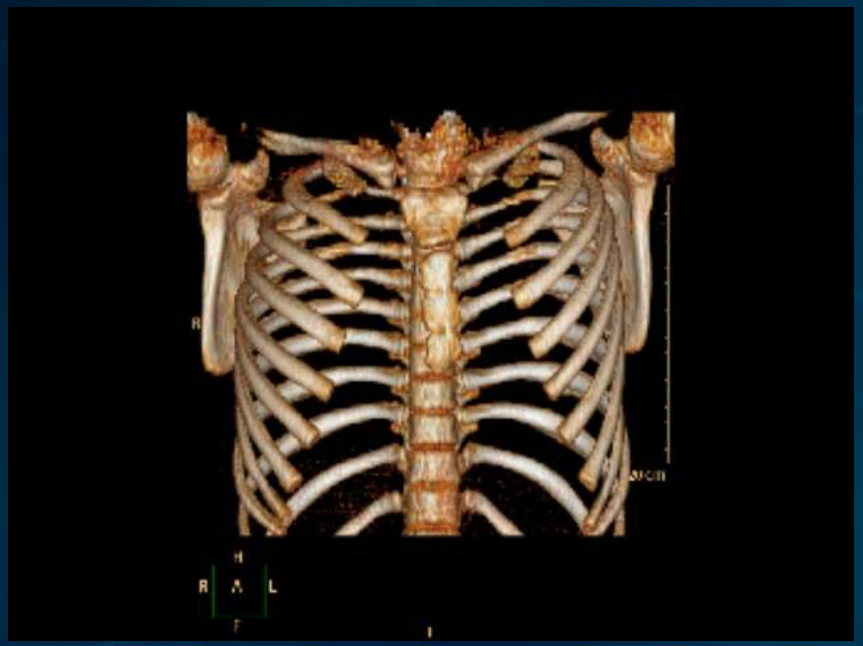
- **Excess Risk: Pearce vs. Ron 1988 tinea capitis study**
  - **estimated doses: Pearce 60.42mGy ; Ron: 1.5G (1,500mGy)**
    - **Pearce: Excess relative risk rate 10X that reported by Ron**
  - **Mathews: IRR for brain cancer raised to 1.51 when scanning *other than the brain***

Ron E. et al Tumors of the brain and nervous system after radiotherapy in childhood. NEJM 1988;319(16):1033

CT

CT – pectus
80 kVp, 20 mAs





CT

ImPACT CT Patient Dosimetry Calculator

Version 1.0.3 24/08/2010

Scanner Model:		
Manufacturer:	Philips	
Scanner:	Philips Brilliance 64 or 40	
kV:	080	
Scan Region:	Body	
Data Set	MCSET20	Update Data Set
Current Data	MCSET20	
Scan range		
Start Position	41	cm
End Position	71	cm
Get From Phantom Diagram		

Acquisition Parameters:			
Tube current		20	mA
Rotation time		1	s
Spiral pitch		1	
mAs / Rotation		20	mAs
Effective mAs		20	mAs
Collimation		40	mm
Rel. CTDI	Lookup	0.75	at selected collimation
CTDI (air)	Lookup	5.2	mGy/100mAs
CTDI (soft tissue)		5.6	mGy/100mAs
$_nCTDI_w$	Lookup	1.8	mGy/100mAs

Organ weighting scheme	ICRP 60

$CTDI_w$	0.4	mGy
$CTDI_{vol}$	0.4	mGy
DLP	11	mGy.cm

Organ	w_T	H_T (mGy)	$w_T.H_T$
Gonads	0.2	0.00041	0.000083
Bone Marrow	0.12	0.14	0.016
Colon	0.12	0.0032	0.00039
Lung	0.12	0.51	0.061
Stomach	0.12	0.077	0.0092
Bladder	0.05	0.00017	8.7E-06
Breast	0.05	0.4	0.02
Liver	0.05	0.13	0.0065
Oesophagus (Thymus)	0.05	0.6	0.03
Thyroid	0.05	0.23	0.011
Skin	0.01	0.11	0.0011
Bone Surface	0.01	0.29	0.0029
Not Applicable	0	0	0
Not Applicable	0	0	0
Remainder	0.05	0.1	0.0051
Not Applicable	0	0	0
Total Effective Dose (mSv)			0.16

Remainder Organs	H_T (mGy)
Adrenals	0.16
Small Intestine	0.0035
Kidney	0.025
Pancreas	0.095
Spleen	0.086
Thymus	0.6
Uterus	0.0007
Muscle	0.11
Brain	0.0048
Not Applicable	N/A
Not Applicable	N/A
Not Applicable	N/A
Not Applicable	N/A

Other organs of interest	H_T (mGy)
Eye lenses	0.0079
Testes	7.7E-06
Ovaries	0.00082
Uterus	0.0007
Prostate	0.00017

Scan Description / Comments	

Introduction | ScanCalculation | Phantom | Paediatric | Scanners | MatchData | Collimation | Mor

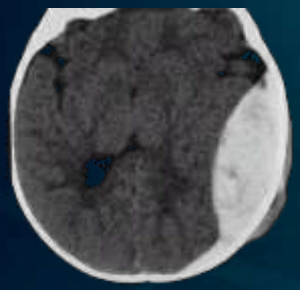
0.24

Moving forward

- Is examination indicated?
- Will it change management?

Chance of death

< 0.1%



100%

- Is non-radiation modality possible
- No multiple scans
- Image only indicated area
- Child-size dose
- Tailor scan to clinical question –pectus vs small mediastinal mass

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- The equipment is appropriate for the test or treatment you will receive, and the facility meets or exceeds quality assurance and safety guidelines.
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image gently Facilities with this logo have successfully achieved accreditation in CT for pediatric imaging. This demonstrates their ability to image pediatric patients with the appropriate radiation doses.

- Diagnostic imaging includes multiple modalities (different types of tests and equipment)—, CT, MRI, mammography, nuclear medicine, PET, breast ultrasound, stereotactic breast biopsy, and ultrasound. The ACR accredits each of these "modalities" separately, so look for accreditation seals for each modality in your hospital's advertisements. Please note that the ACR no longer offers accreditation for general x-ray services.

CT - What's new ?

REVOLUTION

Speed

- Gantry rotation 0.25 seconds
- Temporal resolution 66 milliseconds
- Scan time: 0.15 seconds

CT - What's new ?

REVOLUTION

Dose Reduction

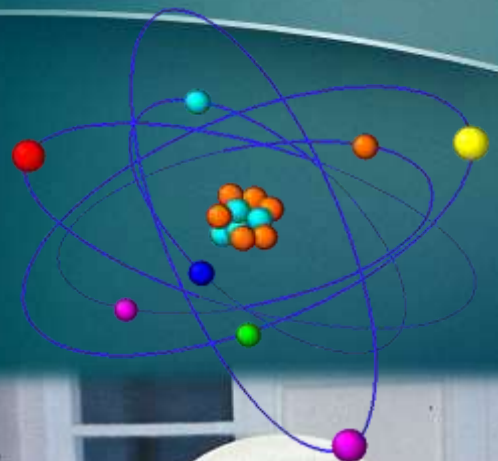
- Better detectors, better collimators
- Reconstruction algorithms
  - Filtered Back Projection
  - Iterative Reconstruction
  - **Model-Based fully Iterative Reconstruction**

CT

	Estimated Dose from Radiologyinfo.org		Dose from new scanners Model-based
Background - Annual at sea level	3mSv		
Cross-country plane flight	0.04 mSv		
CXR	0.1 mSv		
CT Chest	1.5 - 7 mSv		0.06—0.2mSv / 0.25sec
KUB + decubitus	2 mSv		
CT abdomen and pelvis	15mSv		1mSv
Coronary CTA	16 mSv		0.18 mSv

Summary

Image Wisely



Thank you

Image Gently