Radiation Safety in the Computed Tomography Environment

Presented by:
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www.AstaritaAssociates.com

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General Information about Radiation

- Often depicted by books, movies and news media as mysterious, deadly force
- In truth:
  - Nothing mysterious at all
  - Radiation has been studied for over 100 years
  - Detection, measurement and radiation control are extremely common events
  - The more it is understood, the less frightening it becomes
  - A very beneficial diagnostic tool

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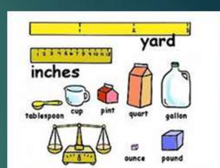
Radiation Quantities and Units

- **Coulomb per kg or Roentgen:**
  - Measure of the exposure of radiation in air
- **Gray or Rad:**
  - Amount of energy (from any type of ionizing radiation) deposited in any medium (e.g. water, tissue, air)
  - 1 Gray = 100 Rads
- **Sievert or Rem**
  - Biological effect of a rad
  - 1 Sievert = 100 Rem



https://www.intuitiveaccountant.com/general-ledger/changing-quickbooks-units-of-measure-no-no-no/#.YAd54-hKhyw

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Radiation Quantities and Units

- **Entrance Skin Exposure**
  - Measurement of radiation output at the point of skin entry for an x-ray examination.
  - Peak skin dose is measured in milligray (mGy)
- **Effective Dose**
  - Measure of potential harm from radiation
  - Effective dose is measured in millisieverts (mSv)

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Natural Background Radiation

- Relatively constant low-level radiation from naturally occurring sources such as the earth (or building materials), cosmic rays, and naturally occurring radionuclides found in the body
- Level of background radiation will vary depending upon location, altitude and the amount of natural radioactive material in the ground
- Highest known background levels recorded in mountains of South America – 10 mSv (1000 millirem) in one year
- Average Natural background in US as stated by the Nuclear Regulatory Commission is 3.1 mSv (310 millirem) per year

http://nuclearsafety.gc.ca/eng/resources/radiation/introduction-to-radiation/types-and-sources-of-radiation.cfm

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Typical Natural Background Radiation Levels

- New York City ~ 3 mSv/yr (300 mRem/yr)
- Denver ~ 5 mSv/yr (500 mRem/yr)
- Grand Central Station > 5 mSv/yr (500 mRem/yr)
- Andes Mountains ~ 10 mSv/yr (1,000 mRem/yr)

https://www.youtube.com/watch?v=DeC_-Sc8Z6s

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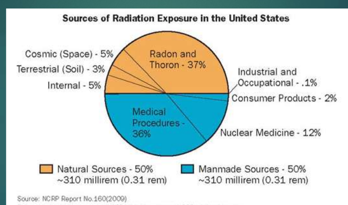
Background Radiation
Natural + Man-Made



www.nrc.gov

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Background Radiation

- No known proven carcinogenic effects from radiation levels in the order of magnitude comparable to background radiation
- Exposures received by **occupational radiation workers** from diagnostic procedures typically fall within background levels

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Effective Dose to Patients

Exam	Dose to patient	B.E.R.T. Background Equivalent Radiation Term (or Time)
Tc99m Sestamibi (12mCi Rest; 36mCi Stress)	12 mSv or 1,200 mRem[1]	4 years
Tl201 (3mCi)	15 mSv or 1,500 mRem[2]	5 years
Cardiac Cath	28 mSv or 2,800 mRem	9 years
CT Angio	12 mSv or 1,200 mRem[3]	4 years
Chest X-ray	0.1 mSv or 10 mRem[3]	10 days

1. ASNC Imaging Guideline for SPECT Nuclear Cardiology Procedures (2016)
2. ICRP Report 106 (2008)
3. ACR.ORG

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Common Doses

Examples	Doses
Flight from Los Angeles to London	0.05 mSv
Annual natural background	3.10 mSv
Barium enema	8.70 mSv
Heart catheterization (skin dose)	260 mSv
Radiation therapy (localized & fractionated)	60,000 mSv

www.hps.org

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Occupational Dose Limits

	Limit
Total Effective Dose Equivalent (Whole body)	0.05 Sv (5 Rem)
Lens of the Eye	0.15 Sv (15 Rem)
Skin/extremity *(shallow dose — 0.007cm deep averaged over 10cm2)*	0.5 Sv (50 Rem)

www.hps.org

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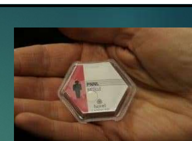
Personnel Monitoring



- Estimates the amount of radiation received by individuals who work around radiation
- Simply measures the amount of radiation to which one was exposed
- Offers no protection against radiation exposure

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Personnel Monitoring

- Required when
  - An individual is likely to receive more than 1/10th the yearly occupational dose limit (i.e. whole body limit: 1/10th of 5000mRem = 500 mRem)
  - An individual handles radioactive material
  - An individual works in a high radiation area (radiation therapy treatment room)
- Therefore, it is usually not necessary to monitor radiology secretaries, file clerks and operating room personnel.
- Whole body monitors are typically worn on the collar and positioned outside the protective apron during fluoroscopic procedures.
- Pregnant workers are to wear a badge at waist level to monitor fetal exposure.

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Personnel Monitoring in CT

- CT personnel are often not monitored due to fixed shielding in the control booth
- Shielding assessed at acceptance testing mitigates the requirement for personnel monitoring.
- If CT Fluoroscopy is an option on the unit, personnel in the room for fluoroscopy procedures will need to be monitored

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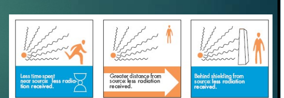
Radiation Safety

Three Cardinal Rules for Radiation Protection:

- Time
- Distance
- Shielding



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ALARA - Time

Minimize your time near a radioactive source or an energized radiation emitting equipment to only what it takes to complete the task.

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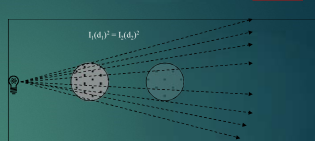
ALARA - Distance

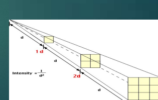
Whenever possible, maintain distance from a known radiation source



Inverse Square Law:

double distance = 1/4 dose

Triple distance = 1/9 dose



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ALARA - Shielding

- Shielding is the most important radiation safety aspect in CT because personnel are typically outside the scan room while exams are in process.
- The shielding layout and the radiation protection survey are performed by a Medical Physicist to ensure the safety of staff

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Radiation Safety in CT

- For Technologist/Staff:
  - Remain outside of the shielded scan room during all CT scans
  - Be aware of all entrances and personnel who may be in the scan room
  - If the unit is capable of performing CT Fluoroscopy:
    - Personal protective equipment (protective garments) must be utilized in the scan room.
  - Time, distance, and shielding practices should always be followed

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Radiation Safety in CT

- To Ensure Patient Safety
  - Always verify the patient and the exam to be performed
  - Facility should perform a routine review of CT protocols by the Radiologist, Medical Physicist and the lead Technologist
  - New protocols should be reviewed by the Medical Physicist or Radiologist
  - Technologists need to be familiar with the CT unit and how each parameter affects patient dose and image quality

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The CT Unit

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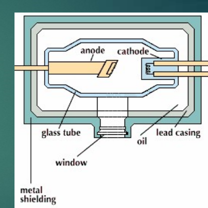
CT X-Ray Production

- X-ray production the same as in general radiography
- Electrons are "boiled off" the cathode and directed toward anode using a potential difference in voltage
- The electrons interact with anode to produce bremsstralung and characteristic x-rays
- Tube is on for entire exam
- Therefore, the cooling system is an integral part when utilizing CT



https://www.fss.txstate.edu/ehsrm/programs/radiation/rpds/xray.html

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All Current CT Units Utilize:

- Rotating X-ray tube within a circular gantry
- Numerous X-ray projections
- Collimated x-ray beam - Increases scatter rejection by detectors
- Highly filtrated beam to create as close to a monoenergetic beam as possible
- Detectors which measure and collect photons - Measurements are made of the transmission and attenuation
- Computer system for Data acquisition
- Image reconstruction algorithms
- Monitors to display finished image

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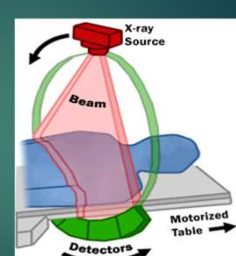
Basic Principles of CT

- Measures the transmission of x-rays from many different directions within a plane of the body
- The cross-sectional image is then reconstructed mathematically



https://www.fda.gov/radiation-emitting-products/medical-x-ray-imaging/computed-tomography-ct

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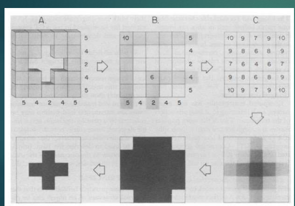
Basic CT Operation



Christensen's Physics of Diagnostic Radiology, Curry et al, Fourth edition

- Displays the basic CT premise using 2 xray projections through a subject
- Figure A displays the attenuation as the xrays pass through the subject. The sums of each solid box are shown for each direction
- Figure B assigns each cell a sum for that location resulting from each projection
- Figure C displays the complete matrix for all the cells
- The next figure assigns a shade of gray for each number value
- The last 2 images are windowed to only show certain values

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What Is $CTDI_{vol}$?

- A standardized parameter to measure Scanner Radiation Output
  - All recent scanners will report the $CTDI_{vol}$ as a reference, prior to the scan, and will produce a report after the scan.
  - Reported in mGy for either a 16-cm diameter acrylic phantom (for head exams) or 32-cm phantom (for body exams)
  - The reported $CTDI_{vol}$ is based on measurements made by the manufacturer in a factory setting
- A Medical Physicist will measure the $CTDI_{vol}$ to verify the correct output of the unit and to ensure protocols meet $CTDI_{vol}$ requirements

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How is $CTDI_{vol}$ related to patient dose?

- $CTDI_{vol}$ is not patient dose
- Patient and composition The relationship between the two depends on many factors, including patient size and composition
- AAPM Report 204 introduces a parameter known as the Size Specific Dose Estimate (SSDE) to allow estimation of patient dose based on $CTDI_{vol}$ and patient size
- For the same $CTDI_{vol}$, a smaller patient will tend to have a higher patient dose than a larger patient

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How is $CTDI_{vol}$ related to patient dose?

120 kVp at 200 mAs — 120 kVp at 200 mAs

http://www.aapm.org/pubs/CTProtocols/documents/CTTerminologyLexicon.pdf

$CTDI_{vol}$ = 20 mGy — $CTDI_{vol}$ = 20 mGy

Both patients scanned with the same $CTDI_{vol}$

Patient dose will be higher for the smaller patient

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How is $CTDI_{vol}$ related to patient dose?

120 kVp at 100 mAs — 120 kVp at 200 mAs

http://www.aapm.org/pubs/CTProtocols/documents/CTTerminologyLexicon.pdf

$CTDI_{vol}$ = 10 mGy, SSDE = 13.2 mGy — $CTDI_{vol}$ = 20 mGy, SSDE = 13.2 mGy

Patients have equivalent SSDE because the protocol was adjusted for patient size

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Why Use $CTDI_{vol}$?

- $CTDI_{vol}$ provides information about the amount of radiation used to perform the study
- $CTDI_{vol}$ is a useful index to track across patients and protocols for quality assurance purposes
- $CTDI_{vol}$ can be used as a metric to compare protocols across different practices and scanners when related variables, such as resultant image quality, are also taken in account
- The ACR Dose Index Registry (DIR) allows comparison across institutions of $CTDI_{vol}$ for similar exam types (e.g., routine head exam)

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Dose Length Product

- The Dose Length Product (DLP) is also calculated by the scanner. It is another reference that can be used similarly to $CTDI_{vol}$
- DLP is the product of the length of the irradiated scan volume and the average $CTDI_{vol}$ over that distance
- Represents integrated dose in terms of total scan length
- DLP has units of mGy*cm
- If the average $CTDI_{vol}$ is 20 mGy for a scan, and the scan is 15 cm in length the resulting DLP = 20 mGy x 15 cm = 300 mGy-cm

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Acquisition Parameter Settings

- Acquisition parameters define the technique that will be used in each protocol
- Acquisition parameters are set in the CT user interface where scans are prescribed
- Changing a single acquisition parameter will affect the resulting CT image and operators of the unit should understand the effect of each change

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CT Acquisition Parameters

- kVp (Kilovoltage Peak)
- mA
- mAs
- Effective mAs
- Time per rotation
- Scan Mode
- Pitch and table feed
- Table increment
- Detector configuration
- Reconstructed slice thickness

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kVp (kiloVoltage peak)

- An increase in kVp will change the x-ray spectrum such that the maximum energy and average effective energy are higher.
- An increase in kVp will increase the amount of photons and the intensity of the beam
- Radiation dose to the patient will be approximately affected by the factor below:

$$\left(\frac{kV_{new}}{kV_{old}}\right)^{n} \qquad Where\ n \approx 2$$

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Exposure Time per Rotation

- The length of time, in seconds, that the X-ray beam is "on" during a single gantry rotation
- Depending on the unit, it may take into account the gantry rotation time and angular acquisition range
- Keeping all other factors the same, patient dose will increase when increasing time per rotation in a directly proportional result. Doubling the exposure time per rotation will double the patient dose and the radiation scatter originating in the room.
- Appropriately using a short time per rotation may also assist in keeping motion low in the images. This is an important factor for pediatric imaging.

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Tube Current (mA)

- Determines the number of electrons to be boiled off the anode and accelerated across the x-ray tube to the cathode. Directly relates to the number of x-ray photons produced.
- Units: milliAmperes (mA)
- Patient dose is directly proportional to Tube Current (mA)
- Keeping all other factors the same, patient dose will increase when increasing mA in a directly proportional result. Doubling the mA will double the patient dose and increase the radiation scatter originating in the room.

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mAs

- The product of Tube Current and the Exposure Time per Rotation
- Since it is the product of both, mAs will affect the image and patient dose the same as the mA and time per rotation in the previous slides
- Units is milliAmpere-seconds (mAs)
- Keeping all other factors the same, patient dose is directly proportional to mAs - same as it is for mA and exposure time per rotation

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Scan Mode

- CT Scanners offer a variety of Scan Modes which describe how the table moves during an exam
- Scan Modes include:
  - Axial scanning - the scan will stop after each rotation to allow the table to move to the next scan location.
  - Helical or Spiral - maintains a continuous exposure as the table and patient move through the gantry
  - Dynamic scanning – only for specific applications which would involve body function such as perfusion studies
- Acquisition Parameters that affect CTDIvol may change amongst different Scan Modes

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Dynamic Scan Mode

- In the Dynamic Scan Mode, the table either does not move while multiple acquisitions are acquired or moves in a modified way such as back and forth. Examples of these study types include:
  - Perfusion Studies
  - Bolus Tracking Studies
  - Test Bolus Studies
- Dynamic Scans may have large $CTDI_{vol}$ values because the scanner typically will report the sum of the $CTDI_{vol}$ values from each rotation

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Table Feed / Table Increment

- Table Feed is the movement of the table through the bore of the scanner over a full 360 degree rotation. Defined as a rate for a helical scan.
- Table Increment is the same concept except it is the movement of the table in between axial scanning exposures. The movement of the table between each individual scan in the series. Axial scans will tend to have a table increment equal to the total beam width to avoid overexposure (if there is an overlap) or missing data (if the increment is greater than the beam width).
- Units: millimeters/rotation for helical scan or millimeters for an axial scan
- Table feed affects patient dose through its inclusion in pitch

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Detector Configuration

- The product of the number of data channels (n) and the width of each detector (T)
- The Detector Configuration determines the Beam Width or Beam Collimation (nT).
- A smaller total beam width will have a higher $CTDI_{vol}$ than a larger beam width. This is due to the scatter contributions of the adjacent beam widths. Scanning with a very low beam width is considered inefficient for most applications.
- User should monitor changes in $CTDI_{vol}$ when changing detector configurations.

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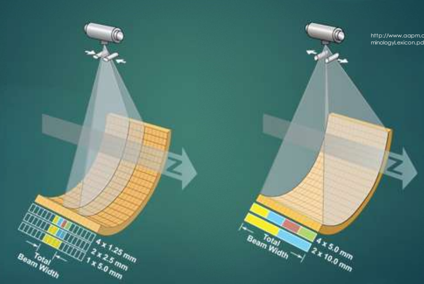
Detector Configuration



http://www.aapm.org/pubs/CTProtocols/documents/CTTerminologyLexicon.pdf

Acquisition Parameter Settings

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Pitch

- Is defined for helical scans only
- Pitch is the table feed per gantry rotation divided by the beam width
- Pitch is the ratio of two distances and therefore has no units
- Patient dose is inversely proportional to pitch. The faster the table moves through the gantry, the higher the pitch, the less exposure to the patient, therefore lower dose.
- Users should monitor other parameters when changing Pitch. The scanner may or may not automatically compensate for changes in pitch (for example, by changing the tube current)

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Pitch

Pitch < 1
Beam Width has some overlap

Pitch = 1
No overlap of Beam Width

Pitch > 1
Table speed per rotation is greater than the beam width. This does not mean areas of the subject are not scanned

http://www.aapm.org/pubs/CTProtocols/documents/CTTerminologyLexicon.pdf

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Effective Tube Current Time Product (Effective mAs)

- Is the product of the Tube Current and the Exposure Time per Rotation <u>divided by the Pitch</u>
- Units: milliAmpere-Seconds (mAs)
- Patient dose is directly proportional to Effective Tube Current Time Product (Effective mAs)
- Not all CT units display effective mAs. It is important to know the difference when operating the CT.

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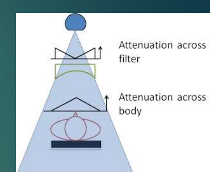
Bow tie filters

- Bow tie filters are placed between the x-ray source and the patient
- Purpose is to remove lower energy x-rays that will not contribute any significant information to image formation but will increase patient dose.
- Removing the lower energy x-rays creates a narrower spectrum of x-ray energies. The result is a more "monochromatic" beam. The basic principle of CT is based upon a monoenergetic beam.



https://sites.google.com/site/frcrphysicsnotes/ct-equipment

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Iterative Reconstruction

- Has replaced filtered back-projection as the most prominent reconstruction process in CT.
- Is a feature that uses the information acquired during the scan as a model and repeats the reconstruction steps to produce an image with less "noise". Noise is the limiting factor of what can be visualized in a CT image. Less noise means better contrast to noise ratios.
- Depending on the type of iterative reconstruction used, the image spatial resolution may also be improved. Ie Physics modeling
- Starts with a model (can be an initial filtered back projection image) and repeats the process to refine the image.

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Iterative Reconstruction

- Utilized by all major Manufacturers
  - GE – ASIR
  - Philips – Idose[4]
  - Siemens – SAFIRE
  - Toshiba – AIDR3D
- Most Important reason for implementing Iterative reconstruction into your protocols:
  - The resulting noise reduction can be utilized to save dose to the patient without a loss in image quality

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Acquisition Parameter Settings Summary

Parameter	Relationship to Patient Dose
Scan Mode	Changes in the Scan Mode may affect patient dose
Table Feed/Increment	Table Feed affects patient dose through its inclusion in Pitch
Pitch	Patient dose $\propto$ 1/Pitch
Detector Configuration	Decreasing the Beam Width typically increases the patient dose
Exposure Time Per Rotation	Patient dose $\propto$ Exposure Time per Rotation
Tube Current (mA)	Patient dose $\propto$ Tube Current (mA)
Tube Potential (kVp)	Patient dose $\propto (kVp_1/kVp_2)^n$ where n is approximately 2
Tube Current Time Product (mAs)	Patient dose $\propto$ Tube Current Time Product
Effective Tube Current Time Product (Effective mAs)	Patient dose $\propto$ Effective Tube Current Time Product (Effective mAs)
Beam Shaping Filter (Bow Tie)	Changes in the Beam Shaping Filter may affect patient dose

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Thank You for Participating

- Please be sure to print out your self attested certificate
- Questions or comments can be directed toward Astarita Associates, Inc. 631-265-2950

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