Radiation Exposure
In Nuclear Medicine

Darlene Metter, MD FACR
DISCLOSURE STATEMENT

I have no relevant financial relationships with commercial interests to disclose.
Ionizing Radiation in Medical Imaging

• > 100 years
• Beneficial to patient care
• New & emerging technologies
• Revolutionized the practice of medicine
Learning Objectives

• Describe the trends in the use of NM procedures

• Identify major sources of radiation exposure to:
  • the patient
  • the technologist

• List 3 occupational radiation safety dose strategies for the NM technologist
Pre-Test
Question #1

• In 2006, the average annual radiation exposure in the US from medical imaging is estimated at:
  
• A. 30%
• B. 40%
• C. 50%
• D. 60%
Question # 2

• Which one of the following is an example of a non-stochastic radiation effect?

• A. Cataracts
• B. Cancer
• C. Genetic defects
• D. Autism
Question # 3

Which one of the following exams has the highest pt radiation exposure?

A. Cardiac ($^{201}$Tl 4 mCi)
B. Cardiac ($^{99m}$Tc 40 mCi, 1 day)
C. Octreoscan ($^{111}$In 6 mCi)
D. $^{18}$FDG 20 mCi
Question # 4

• Which NM technologist task is generally associated with the highest work-related dose?

• A. Radiopharmaceutical preparation
• B. Radiopharmaceutical injection
• C. Patient scanning
• D. Patient transfers
Question # 5

Which NM procedure is generally associated with the highest occupational dose to the NM tech?

A. Bone SPECT
B. MUGA
C. $^{131}$I WB post therapy scan
D. Stress $^{99m}$Tc MIBI
Current Trends/Usage of NM Procedures
Current Trends/Usage of NM Procedures

• 2007 US medical procedures: highest source of ionizing radiation to the public

• Inc in diagnostic imaging using ionizing radiation (F Mettler, 2008)
  – CT, vascular interventional, NM
ACR Response: White Paper*

- 2007 ACR Blue Ribbon Panel on Radiation Dose in Medicine
- To assess current dose issue in medical procedures
- Develop guidelines to protect & inform the public

Amis et al “ACR White Paper on Radiation Dose in Medicine”
2007 JACR Vol 4 (5). P 272-284
ACR Panel Conclusion

1. Education of stakeholders in radiation safety
2. Appropriate utilization of imaging
3. Standardization of radiation dose data for archiving: benchmarking good practice
4. Identify pts who have reached certain thresholds; alternate imaging?
2011 GILBERT W. BEEBE SYMPOSIUM

TRACKING RADIATION EXPOSURE FROM MEDICAL DIAGNOSTIC PROCEDURES

December 8-9, 2011

The National Academies
Keck Center
Room 100
500 Fifth Street, NW
Washington, DC 20001

The symposium is open to the public

Includes Nat Acad of Science; Nat Acad of Engineering; IOM; National Research Council
Concern over potential health risks from the dramatic increase of radiation exposure due to medical diagnostic procedures in the population has been expressed by a number of stakeholders. Join us as we discuss the “why”, “what” and “how” to track exposures. A National Academies report will be prepared that summarizes the symposium presentations and discussions.

1.5 day meeting with ACR input
Increasing public concern*

Siemens launches informational websites on medical radiation
Siemens Healthcare has launched www.medicalradiation.com, an informational website intended to educate patients and the general public about medical radiation. The company has also launched www.siemens.com/low-dose, a low-dose information site for doctors and clinical personnel. AuntMinnie.com (free registration) (11/27)

Boost Healthcare Recruitment with Employee Engagement
Learn how you can attract a consistent flow of great healthcare candidates and reduce turnover with employee engagement. Find out what employment experts are referring to when they speak of “employee engagement”, and how you can use this practice to make your life easier...saving time, money and frustration. Download your free copy now.

Experts offer tips on how to talk about dose risks with patients
When talking about the radiation risks from an imaging procedure with patients, it is important to use simple language, which means avoiding the use of too much jargon and complicated information, experts said during a radiology group’s meeting. It is also important to emphasize the benefits of a certain procedure versus the risks, since radiologists and the media seldom discuss the benefits of imaging tests, one expert said. MolecularImaging.net (11/27)

* SNM Smart Brief 11/28/2011
ACR Panel Report

- **1980**
  - CT 3 million
  - NM 7 million

- **2005**
  - CT 60 million
  - NM 20 million
## Est # NM Exams (X1000) (US)*

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* Mettler FA 2008 “Medical Effects of Ionizing Radiation
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Gamma Camera Sales

• 11/23/11 Global Industry Analysts, Inc

• Report: global market for gamma cameras projected to inc to $846.6 million by 2017

• US is the largest global market

• Why? Aging pop, inc death rate assoc w/ cancer, cardiac & CNS disease

• Inc public awareness of advanced imaging
What About PET?

• Bio-Tech Sys of Las Vegas: market researcher providing insight into new technologies & trends

• **Predict**: PET procedures to increase

• SPECT: 2010 $758 million to 2018 $1.68 billion
Why?

• Wider availability of FDG & PET technology
• Wider physician & patient acceptance
• Increased approved indications (ie reimbursement)
• Emerging novel tracers: oncology, cardiology, neurology
PET Procedures

• 2009: increase 9%
• 2010: increase 9%
• PET agents:
  – 2010 $391.8 million
  – 2018 $4.31 billion

• CMS reimbursement issues, but PET users adapted to reimbursement requirements

* Bio-Tech Systems
** NOPR 2006-09 expanded CMS coverage; NOPR 2009
FDG Sales

• Reflection of PET procedures

• 2009: $300 million for FDG

• 2017: projected $800 million for FDG

• 2017: projected $3.43 billion for all PET RP
Average Annual Radiation Exposure*

- 1987: radon/NORM majority medical imaging 15% (XR, NM)
- 2006: medical imaging 51% radon 30% internal/therapies 6% cosmic 6%

* Mettler FA 2008 “Medical Effects of Ionizing Radiation”
Average Annual Radiation Exposure*

• 1987: radon/NORM majority medical imaging 15% (XR, NM)

• 2006: medical imaging 51% radon 30% internal/therapies 6% cosmic 6%

• US avg: 6.27 mSv/y (WW: 2.4 mSv/y)

• Mettler FA 2008 “Medical Effects of Ionizing Radiation
Radon

- Decay product of uranium
- $t^{1/2}$: 4.5 billion yr
- Largest component in background radiation, granite bedrock (earth’s crust)
  - 3 mSv or 300 mrem/yr per person in US
- Gas accumulating in buildings:
  - attics, basements
  - indoor air contaminant
  - Texas: low–mod potential
    NO high potential
ACR Panel Report

• Japanese atomic bomb survivor data
  – most compreh epidemic study supporting radiation induced carcinogenesis
• Statistically significant increase in CA at doses > 50 mSv; below ?? - controversial
• CT-NM studies dose estimates: 10-25 mSv/study
• Implication of multiple studies
ACR Panel Report

“1 yr collective dose estimate from medical procedures in the US = total WW collective dose generated by the nuclear catastrophe at Chernobyl”
ACR Panel Report

• Radiation induced CA latency: 10-20 years or longer
• Effects of current inc dose not evident for many years
• Difficult to attribute “radiation induced CA” from a study from normal risk*
  ~ 40% of population dx w/ CA in lifetime

* Can’t distinguish radiation induced CA from others
Review: Trends in NM Procedures

• Since 1980, inc number of NM proced
• Major sources of radiation to public:
  - A SIX fold increase in 26 years!
  - radiation & radon
• Mettler (2008) - population per caput annual dose from medical radiation:
  - 1980: 0.54 mSv
  - 2006: 3.2 mSv (> bkgd 2.3 mSv)

* Huda W, Mettler FA Radiol: Vol 258(1) Jan 2011; p 236-242

Or a 600% increase in one generation
Question #1

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NM PROCEDURE DOSES TO: the PATIENT
Understanding Patient Exposure

• Most physicians do not understand
• **Goal:** education; can then weigh a procedure’s risks & benefits
• Mettler:
  – NM study avg pt dose: **0.3-20 mSv**
  – average annual effective dose from background radiation: **2.5-3 mSv**
Radiation Protection in US

- Before 1950, concern was occupational exposure
- Mid-1950s, public concern included
  - patient & individual
  - population: progeny, genetic pool as a whole
Terminology

1. Stochastic vs Non-stochastic effects

2. Quantification of radiation exposure
Stochastic Effects*

• “Effects that occur by chance, generally occurring without a threshold level of dose, whose probability is proportional to the dose and whose severity is independent of the dose. In the context of radiation protection, the main stochastic effects are cancer and genetic effects.”

NRC website: www.nrc.gov
Stochastic Effects

• Uncertain if chronic low dose radiation leads to adverse latent effects: CA

• Appears most low dose radiation $\rightarrow$ cellular repair $\rightarrow$ no adverse effects

• What are the adverse cellular effects of radiation?
Radiation: Adverse Cellular Effects

- Cells vary in radiosensitivity ("cell death"*)
  - degree of proliferation, differentiation, duration of mitosis

- Cell radiosensitivity: function of cell type
  - Low: non-dividing, fixed post-mitotic
    - mature RBC, bone, cartilage
    - muscle, ganglion cells
    - mature connective tissue

- Radiation cell death caused by the double-stranded DNA break
Radiation: Adverse Cellular Effects

- **High**: less differentiated, divide quickly
  - Lymphocytes, immature hematopoietic, intestinal epithelium, spermatogonia, ovarian follicular cell
BEIR Committee

• National Academy of Science: Biological Effects of Ionizing Radiation Committee
• Claims future CA risk for low level ionizing radiation uses a non-threshold, linear model for cancer induction
• Data: atomic bomb survivors
BEIR VII*

- Supports “linear-no-threshold” model

- CA risks proceeds linearly at low doses w/o a threshold, smallest dose has the potential to cause a small inc in CA risk

- Low dose: up tp 100 mSv

* Biologic Effects of Ionizing Radiation (June 2005), Nat Acad Sciences
One 100 mSv exposure

1 Cancer

BUT other 42 are naturally occurring.

Figure 2. In a lifetime, approximately 42 (solid circles) of 100 people will be diagnosed with cancer\textsuperscript{2} from causes unrelated to radiation. The calculations in this report suggest approximately one cancer (star) in 100 people could result from a single exposure 100 mSv of low-LET radiation.
Background Cancer in Population

• Cancer diagnosis: ~ 42/100 people

• 1/1000 could be from a single 10 rem (0.1 Sv) dose above background radiation*

• Since the BEIR Committee assumes the linear no threshold model, risks from cancer can be calculated

* BEIR VII report
Stochastic Effects

• But there appears to be a threshold to adverse effects at 0.05-0.1 Sv, but to be conservative, NRC assumes:
  – no threshold
  – linear response
  – ALARA principle
ALARA Principle

• “As-Low-As-Reasonably-Achievable”
• 3 tenets: time, distance, appropriate shielding
• ALARA I: 125 mrem/quarter
• ALARA II: 375 mrem/quarter
• Helps to set “checkpoints,” if reached should justify investigation & action
Non-Stochastic Effects*

- “The health effects of radiation, the severity of which vary with the dose and for which a threshold is believed to exist. Radiation-induced cataract formation is an example of a non-stochastic effects (also called a deterministic effect).”
Radiation Cataractogenesis

- Non-linear
- Dose-related threshold: ~2 Gy/200 rad
- Doses > 7 Gy: 100% cataracts
- Latency: ~ 15 yrs
- High LET, greater RBE (factor 2 or >)
  - e.g. shorter duration at a higher dose, faster cataract formation
Radiation Effects

- **Stochastic**
  - Severity: independent of dose
  - Probability of occurrence: inc with dose
  - Threshold: No

- **Non-stochastic**
  - Severity: increases with dose
  - Probability of occurrence: inc with dose
  - Threshold: Yes
Question # 2

- Which one of the following is an example of a non-stochastic radiation effect?
  - A. Cataracts
  - B. Cancer
  - C. Genetic defects
  - D. Autism
Question # 2

• Which one of the following is an example of a non-stochastic radiation effect?

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Quantification of Radiation Exposure
Quantification of Radiation Exposure

- Measured quantities
- Exposure
- Absorbed dose
- Equivalent dose
- Effective dose
Quantification of Radiation Exposure

- **Measured quantities**: (Curie, Ci; Bequerel, Bq) administered activities
- Exposure
- Absorbed dose
- Equivalent dose
- Effective dose
Quantification of Radiation Exposure

- Measured quantities
- **Exposure**: (Coulomb/kg; Roentgen, R) exposure in air; amt of X- or gamma rays producing a given amt of ionization in each unit of air
- Absorbed dose
- Equivalent dose
- Effective dose
Quantification of Radiation Exposure

- Measured quantities
- Exposure
- **Absorbed dose**: (Gray, Gy; rad) amt of energy absorbed per unit mass
- Equivalent dose
- Effective dose
Quantification of Radiation Exposure

- Measured quantities
- Exposure
- Absorbed dose
- **Equivalent dose**: (Sievert, Sv, rem) absorbed dose $\times$ quality factor; QF for photons = 1 (beta, gamma); quantifies biologic harm to tissue related to type of radiation
- Effective dose
Quantification of Radiation Exposure

- Measured quantities
- Exposure
- Absorbed dose
- Equivalent dose

- **Effective dose:** (Sievert, Sv; rem) equiv dose X tissue weighting factor; whole body dose estimates via dose to & sensitivity of each organ; calculated; allows comparison between ionizing radiation sources
Effective Dose

• “Individual dose is best calculated by determining the mean doses to all radiosensitive tissue combining with age, sex & organ specific coefficients.”

• Example:
  – avg EDE background radiation: 2.5 mSv/y
  – EDE chest xray: ~ 0.1 mSv
  – Annual dose near Chernobyl: ~ 6 mSv/y
Effective Dose

• Calculations based on anthropomorphic phantoms with internal dosimeters or by the Monte Carlo method of computational algorithms – easy to measure

• Patient actual dose from a NM procedure: very difficult
Public Information
- News and Events
- Position Statements
- Nuclear

Resources
- Radiation Dose Chart
- Brochures
- Glossary
- Frequently Asked Questions
- Top 10 Myths about Nuclear Energy
- Multimedia
- Exhibits
- Crossword Puzzles

Nuclear Science Badge Workshop
How to Host a Juniors Girl Scout Workshop
Radiation Dose Chart

We live in a radioactive world - humans always have. Radiation is part of our natural environment. We are exposed to radiation from materials in the earth itself, from naturally occurring radon in the air, from outer space, and from inside our own bodies (as a result of the food and water we consume). This radiation is measured in units called millirems (mrem).

The average dose per person from all sources is about 620 mrem per year. It is not, however, uncommon for any of us to receive less or more than that in a given year (largely due to medical procedures we may undergo). International Standards allow exposure to as much as 5,000 mrem a year for those who work with and around radioactive material.

Common Sources of Radiation

All figures for radiation exposure are average values.

<table>
<thead>
<tr>
<th>Where You Live</th>
<th>Your Annual Dose</th>
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</thead>
<tbody>
<tr>
<td>Cosmic Radiation (from outer space)</td>
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<tr>
<td>Exposure depends on your elevation (how much air is above you to block radiation). Amounts listed are per year.</td>
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<tr>
<td>at sea level (25 mrem)</td>
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<tr>
<td>Elevation: Atlanta 1050; Chicago 305; Dallas 430; Denver 5280; Las Vegas 2000; Minneapolis 815; Pittsburg 1200; St. Louis 455; Salt Lake City 4400; Spokane 1800. USGS G11S Search</td>
<td>25 mrem</td>
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<tr>
<td>Terrestrial (from the ground)</td>
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<tr>
<td>I live in a state that borders the Gulf or Atlantic coasts (16 mrem)</td>
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<td>I live in the Colorado Plateau area (around Denver) (53 mrem)</td>
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<td>I live elsewhere in the continental U.S. (30 mrem)</td>
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<td>House Construction</td>
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<td>Category</td>
<td>Description</td>
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<tr>
<td>House Construction</td>
<td>I live in a stone, adobe, brick, or concrete building (7 mrem)</td>
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<td>Power Plants</td>
<td>I live within 50 miles of a nuclear power plant (0.01 mrem)</td>
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<td>I live within 50 miles of a coal-fired power plant (0.03 mrem)</td>
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<tr>
<td>Food, Water, and Air</td>
<td>Internal Radiation *</td>
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<td>From food (Carbon-14 and Potassium-40) and from water (radon dissolved in water)</td>
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<td>From air (radon)</td>
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<td>How You Live</td>
<td>Jet plane travel hours:</td>
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<td>(0.5 mrem per hour in the air)</td>
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<td>I have porcelain crowns or false teeth (0.07 mrem) **</td>
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<td>I’ve gone past luggage x-ray inspection at the airport (0.002 mrem)</td>
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<td>I view a TV or computer screen which uses CRT technology (1 mrem) †</td>
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<td>I smoke 1/2 pack of cigarettes every day of the year (18 mrem)</td>
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<td>I have a smoke detector (2,000 mrem)</td>
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<td>Medical Tests</td>
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<td><strong>Medical Diagnostic Tests</strong></td>
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<td>Number of millirems are per procedure and are average values. Actual numbers may vary. Enter the number of procedures per year.</td>
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<td>X-Ray - Upper GI</td>
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<td>Procedure</td>
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<td>X-Ray - Extremity (hand/foot)</td>
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<td>CT Scans - Spine</td>
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<tr>
<td>CT Scans - Whole Body</td>
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<tr>
<td>CT Scans - Cardiac</td>
<td>(2000 mrem)</td>
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Your Estimated Annual Radiation Dose: 324 mrem
NM Procedures: Sources of Patient Doses

1. General
2. CT:
   - SPECT/CT
   - PET/CT
3. PET tracers

5 min

5 min
NM Procedures : Sources of Patient Doses

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</tr>
<tr>
<td>Bone</td>
<td>80</td>
<td>220</td>
<td>1300</td>
<td>3450</td>
</tr>
<tr>
<td>Lung</td>
<td>330</td>
<td>600</td>
<td>900</td>
<td>740</td>
</tr>
<tr>
<td>Thyroid</td>
<td>450</td>
<td>630</td>
<td>650</td>
<td>&lt;100</td>
</tr>
<tr>
<td>CV</td>
<td>25</td>
<td>50</td>
<td>600</td>
<td>9800</td>
</tr>
<tr>
<td>Total</td>
<td>3230</td>
<td>4800</td>
<td>5850</td>
<td>19,000</td>
</tr>
<tr>
<td>Pop (10^7)</td>
<td>209</td>
<td>215</td>
<td>227</td>
<td>300</td>
</tr>
</tbody>
</table>
Growth in Imaging

- **CARDIAC**
  - 1970: 25,000
  - 2005: 9,800,000
  - Effective dose: ~10 mSv or 1 rem

- **BONE**
  - 1970: 80,000
  - 2005: 3,450,000
  - Effective dose: 5.2 mSv (24 mCi MDP)
Effective Dose in NM Imaging

- > 85% labeled with Tc$^{99m}$
- 100-1100 MBq (2.7-29.8 mCi)
- ED: 1-10 mSv
- PET/CT ED: 20-37 mSv (2-3.7 rem)
  - FDG: 14.1 mSv (20 mCi)
  - CT: 10-15 mSv
<table>
<thead>
<tr>
<th></th>
<th>ED (mSv)</th>
<th>mCi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brain: HMPAO</td>
<td>6.9</td>
<td>20</td>
</tr>
<tr>
<td>FDG</td>
<td>14.1</td>
<td>20</td>
</tr>
<tr>
<td>Thyroid: $^{123}$I</td>
<td>1.9</td>
<td>0.15</td>
</tr>
<tr>
<td>TCO$_4$</td>
<td>4.8</td>
<td>10</td>
</tr>
<tr>
<td>Parathyroid</td>
<td>6.7</td>
<td>20</td>
</tr>
<tr>
<td>MUGA</td>
<td>7.8</td>
<td>30</td>
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</table>
Effective Doses in NM

<table>
<thead>
<tr>
<th></th>
<th>ED (mSv)</th>
<th>mCi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cardiac: $^{201}$Tl</td>
<td>37</td>
<td>4</td>
</tr>
<tr>
<td>MIBI (2 d)</td>
<td>12.8</td>
<td>40</td>
</tr>
<tr>
<td>MIBI (1d)</td>
<td>9.4</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>11.4</td>
<td>40</td>
</tr>
<tr>
<td>FDG</td>
<td>14.1</td>
<td>20</td>
</tr>
<tr>
<td>Lung: MAA</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>$^{133}$Xe</td>
<td>0.5</td>
<td>20</td>
</tr>
<tr>
<td>DTPA</td>
<td>0.2</td>
<td>35</td>
</tr>
<tr>
<td>GI Bleed</td>
<td>7.8</td>
<td>30</td>
</tr>
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</table>
## Effective Doses in NM

<table>
<thead>
<tr>
<th></th>
<th>ED (mSv)</th>
<th>mCi</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Renal:</strong> DTPA</td>
<td>1.8</td>
<td>10</td>
</tr>
<tr>
<td><strong>MAG3</strong></td>
<td>2.6</td>
<td>10</td>
</tr>
<tr>
<td><strong>DMSA</strong></td>
<td>3.3</td>
<td>10</td>
</tr>
<tr>
<td><strong>GH</strong></td>
<td>2.0</td>
<td>10</td>
</tr>
<tr>
<td><strong>Bone:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>6.3</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>5.2</td>
<td>24</td>
</tr>
<tr>
<td></td>
<td>3.5</td>
<td>16</td>
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</tbody>
</table>
Effective Doses in NM

<table>
<thead>
<tr>
<th></th>
<th>ED (mSv)</th>
<th>mCi</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{67}$Ga</td>
<td>15</td>
<td>4</td>
</tr>
<tr>
<td>Octreoscan</td>
<td>26</td>
<td>6</td>
</tr>
<tr>
<td>WBC: $^{111}$In</td>
<td>7</td>
<td>0.5</td>
</tr>
<tr>
<td>HMPAO</td>
<td>8.1</td>
<td>20</td>
</tr>
<tr>
<td>Tumor: FDG</td>
<td>14</td>
<td>20</td>
</tr>
<tr>
<td>PET/CT</td>
<td>37</td>
<td></td>
</tr>
<tr>
<td>MIBG: $^{131}$I</td>
<td>7.4 mSv/mCi</td>
<td>0.5-1</td>
</tr>
<tr>
<td>$^{123}$I</td>
<td>0.67 mSv/mCi</td>
<td>5-10</td>
</tr>
</tbody>
</table>
## Effective Doses in NM

<table>
<thead>
<tr>
<th>Procedure/Tracer</th>
<th>ED (mSv)</th>
<th>mCi</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{67}$Ga</td>
<td>15</td>
<td>4</td>
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<td>6</td>
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<td>WBC: $^{111}$In</td>
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<td>0.5</td>
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<td>HMPAO</td>
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<td>20</td>
</tr>
<tr>
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<td>20</td>
</tr>
<tr>
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<td>$^{123}$I</td>
<td>0.67 mSv/mCi</td>
<td>5-10</td>
</tr>
</tbody>
</table>
$^{111}$In Octreotide SPECT/CT*

- Package insert, 70 kg pt
- 4.35 mSv/mCi
- 6 mCi = 26 mSv (SPECT)
- CT: 10 mSv
- SPECT/CT: 26 + 10 = 36 mSv

*Sheu et al U of Pittsburgh MC “SPECT/CT and PET/CT: What Radiation Dose are Your Patients Getting and What Does It Mean to Them? 2010 RSNA
NM Imaging

• So what does this all mean?
• How does one quantitate this?
• How does this relate to one’s cancer risk?
ACR Website

- Equates studies with a time equivalent of background radiation and cancer risk

- **NOTE**: 1 in 5 will die from CA

- Risk of dying from CA due to exam:
  - v low: 1 in $10^4$ to $10^5$
  - low: 1 in $10^3$ to $10^4$
  - moderate: 1 in 500 to $10^3$
## Equivalence (background radiation) and CA Risk

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Radiation Dose (mSv)</th>
<th>Duration (yr/mon)</th>
<th>Risk Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abd/pelv</td>
<td>15</td>
<td>5</td>
<td>low</td>
</tr>
<tr>
<td>Abd/pelv: -/+</td>
<td>30</td>
<td>10</td>
<td>mod</td>
</tr>
<tr>
<td>Coronary CTA</td>
<td>16</td>
<td>5</td>
<td>low</td>
</tr>
<tr>
<td>Ca++ score</td>
<td>3</td>
<td>1</td>
<td>low</td>
</tr>
<tr>
<td>CT colon</td>
<td>10</td>
<td>3</td>
<td>low</td>
</tr>
<tr>
<td>BE</td>
<td>8</td>
<td>3</td>
<td>low</td>
</tr>
<tr>
<td>Spine</td>
<td>6</td>
<td>2</td>
<td>low</td>
</tr>
<tr>
<td>Chest</td>
<td>7</td>
<td>2</td>
<td>low</td>
</tr>
<tr>
<td>Chest CTA/PE</td>
<td>15</td>
<td>5</td>
<td>low</td>
</tr>
<tr>
<td>Head</td>
<td>2</td>
<td>8 mo</td>
<td>very low</td>
</tr>
</tbody>
</table>
Extrapolate the Dose to NM procedures

- **Mod risk:** $^{201}$TI 37 mSv: 4 mCi
  - Octreoscan SPECT/CT: 36 mSv
  - FDG/PET CT: 20-37 mSv
  - $^{67}$Ga 30 mSv: 8 mCi

- Risk of dying from CA: 1 in 500 to 1000
Extrapolate the Dose to NM procedures

- **Low risk**: Cardiac $^{99m}$Tc (MPI, MUGA)
- MDP, WBC
- Brain HMPAO/FDG
- V/Q, GI & GU
- MIBG, Thyroid/parathyroid

- Risk of dying from CA: 1 in 1000 to 10,000 (from the exam)
# Procedure Equivalence (CXR)

<table>
<thead>
<tr>
<th>Study</th>
<th>Eff Dose (mSv)</th>
<th># CXR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dental</td>
<td>0.005-0.01</td>
<td>0.25-0.5</td>
</tr>
<tr>
<td>CXR</td>
<td>0.1</td>
<td>1</td>
</tr>
<tr>
<td>MMG</td>
<td>0.4</td>
<td>20</td>
</tr>
<tr>
<td>CT</td>
<td>2-16</td>
<td>100-800</td>
</tr>
<tr>
<td>NM</td>
<td>0.2-41</td>
<td>10-2050</td>
</tr>
<tr>
<td>Interventional Fluoroscopy</td>
<td>&gt;70</td>
<td>250-3500</td>
</tr>
</tbody>
</table>
Question # 3

• Which one of the following exams has the highest pt radiation exposure?

• A. Cardiac (\(^{201}\)Tl, 4 mCi)
• B. Cardiac (\(^{99m}\)Tc , 40 mCi, 1 day)
• C. Octreoscan (6 mCi)
• D. \(^{18}\)F FDG 20 mCi
Question # 3

• Which one of the following exams has the highest pt radiation exposure?

• A. Cardiac ($^{201}$TI, 4 mCi)
CT Dose Reduction
CT Acquisition Parameters

- **kVp**: kinetic energy of the electron; inc kVp → inc dose; inc penetrating power; dec contrast (~ 120 kVp)
- **mAs**: photon flux; inc mAs → inc # photons, inc dose (~ 120 mAs or >)
- **Pitch**: how far CT table travels per xray source rotation; inc pitch → dec dose: dec z-axis resol + recon artifact
Which Parameter Has a Greater Effect on Dose: kVp or mAs?

<table>
<thead>
<tr>
<th>kVp</th>
<th>mAs</th>
<th>Brain (mGy)</th>
<th>Eye</th>
</tr>
</thead>
<tbody>
<tr>
<td>90</td>
<td>25</td>
<td>1.39</td>
<td>1.94</td>
</tr>
<tr>
<td>90</td>
<td>300</td>
<td>17.00</td>
<td>20.31</td>
</tr>
<tr>
<td>120</td>
<td>25</td>
<td>3.21</td>
<td>3.71</td>
</tr>
<tr>
<td>120</td>
<td>300</td>
<td>37.79</td>
<td>49.72</td>
</tr>
<tr>
<td>140</td>
<td>25</td>
<td>5.08</td>
<td>5.44</td>
</tr>
<tr>
<td>140</td>
<td>300</td>
<td>65.07</td>
<td>69.75</td>
</tr>
</tbody>
</table>
Which Parameter Has a Greater Effect on Dose: kVp or mAs?

<table>
<thead>
<tr>
<th>kVp</th>
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<th>Eye</th>
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<tr>
<td>90</td>
<td>25</td>
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<td>1.94</td>
</tr>
<tr>
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</tr>
<tr>
<td>120</td>
<td>25</td>
<td>3.21</td>
<td>3.71</td>
</tr>
<tr>
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<td>300</td>
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<td>25</td>
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</tr>
<tr>
<td>140</td>
<td>300</td>
<td>65.07</td>
<td>69.75</td>
</tr>
</tbody>
</table>

**RESULTS:** Inc dose with inc kVp & mAs, but the inc with mAs is linear, the inc with kVP is squared.
Strategies to Decrease Pt Dose

• Modulate kVp & mAs depending on pt size & body part scanning

• **Use low dose for:**
  – localization (dec dose: 50-65%)
  – attenuation correction (dec dose: 97%)
  – chest CT (lung)
  – small patient
Other Strategies to Consider

- Appropriateness of the procedure
- Dec radiopharmaceutical doses (incl. imaging time)
- Dec CT acquisition parameters if a diagnostic CT will not add to the current available information
NM PROCEDURE DOSES
TO: the TECHNOLOGIST
US NRC Maximal Annual Permissible Limits for Occupational Exposure

- Whichever is more limiting:
  - **Total EDE OR** 50 mSv
  - Sum of deep DE to org/tissue **500 mSv** (except lens)
- Shallow DE to **skin/extremity** 500 mSv
- **Eye/lens** (nonstochastic) 150 mSv
- Minors (<18 yrs) 10% of above
3 Tenets of ALARA

- Time
- Distance
- Appropriate shielding
Time

• Greater time near a radiation source → greater exposure

• Major radiation source:

• Common clinical settings:
  – dosing room, patient transfers (to and from the imaging room/table), imaging time, uptake time, waiting time
Time

- Greater time near a radiation source → greater exposure
- Major radiation source: the patient
- Common clinical settings:
  - dosing room, patient transfers (to and from the imaging room/table), imaging time, uptake time, waiting time
Why are the technologists here?
While the patient is here?
Limit their occupational dose.
Time Suggestion Strategies

- Be aware of the proximity of injected patients
- Explain proced/pt questions before inject RP
- Hall or room where injected pt are waiting to be scanned (take an alternate route)
- Injected patient bathroom (use alternate)
- Video tracking of pt
- Work related phone or “break” near injected patients (move the phone)
- Wait for tracer to decay
Distance

- The “Newton’s Inverse Square Law”
- The intensity of radiation is inversely proportional to the square of the distance from the source.

Intensity = $1/d^2$
Distance

• The intensity of radiation becomes weaker as it spreads out from the source since the same amount of radiation is spread over a larger area.

• Example: Heat from a fireplace
Shielding

• Depending on the type of ionizing radiation, use appropriate shielding

• **alpha radiation**: No shielding, poor penetration, high energy
  – major concern: internal contamination by ingestion, absorption or inhalation

Polonium 210
Alpha Radiation Precautions

• Apply basic lab safety: **NO** eating, drinking, smoking, or applying make-up in the radiopharmacy or clinic.
Shielding

• Alpha radiation precautions:
  • Personal Protective Equipment (PPE)
    – laboratory coat
    – gloves (esp if skin is not intact)
    – other
Shielding

- **Beta radiation:**
  - Low Z shielding – plastic, glass
  - No high Z due to Bremsstrahlung radiation which is highly penetrating
Shielding

• Gamma radiation, PET tracers:
  • High Z shielding with the amount dependent on the energy of the radiation & HVL of the shielding material
  • Generally, 10 HVL needed to achieve background radiation
<table>
<thead>
<tr>
<th>Radioisotope</th>
<th>keV</th>
<th>HVL Pb (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{99m}$Tc</td>
<td>140</td>
<td>~0.02</td>
</tr>
<tr>
<td>$^{131}$I</td>
<td>364</td>
<td>~0.30</td>
</tr>
<tr>
<td>$^{133}$Xe</td>
<td>81</td>
<td>~0.03</td>
</tr>
<tr>
<td>$^{111}$In</td>
<td>245</td>
<td>~0.10</td>
</tr>
<tr>
<td>$^{137}$Cs</td>
<td>662</td>
<td>~0.65</td>
</tr>
<tr>
<td>$^{201}$Tl</td>
<td>70</td>
<td>~0.03</td>
</tr>
<tr>
<td>$^{125}$I</td>
<td>35.5</td>
<td>~0.01</td>
</tr>
</tbody>
</table>
## HVL in NM

<table>
<thead>
<tr>
<th>Radioisotope</th>
<th>keV</th>
<th>HVL Pb (cm)</th>
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</tr>
</tbody>
</table>
Shielding


• **Conclusion:** 2 mm lead shield dec NMT dose by $\frac{1}{2}$ for common proce.

- $\text{TCO}_4$ thyroid, bone, cardiac
- MIBI & thallium, DMSA
- highest dose: MIBI cardiac
FDG shielded shipping box and syringe shield.

Weight: 70 #

Courtesy of J Thomas
Windowed

FDG Syringe Shields

No window

Courtesy of J Thomas
FDG syringe shield and pig

Courtesy of J Thomas
Radiopharmacy

Wheeled cart with FDG in syringe shield enroute to dosing room.

Courtesy of J Thomas
Occupational Radiation Exposure

• Primary exposures for NM technologist:
  – radiopharmaceutical preparation
  – injecting patients
  – radioactive patients
Occupational Radiation Exposure

• Primary exposures for NM technologist:
  - radiopharmaceutical preparation
  - injecting patients
  - radioactive patients
Occupational Radiation Exposure Issues

• Devise strategies to reduce work-related exposure.

• What tasks expose the NMT to the highest radiation dose?
Work-related Tasks

1. Radiopharmaceutical preparation/administration
2. Patient transfers to & from the imaging room; on & off the imaging table
3. Patient imaging to include “set up”
4. Therapeutic procedures
5. PET studies
Question

• How can one minimize exposure during those tasks with the highest radiation dose?

• ALARA principle & monitoring
Badges: Monitor Work-Related Dose

1. Who needs to be badged?

2. Where are the badges worn?
Badge requirements

- Anybody who is likely to receive > 10% of occupational dose limits
- Any minor or pregnant female likely to receive >100 mrem
- Where are badges worn?

Courtesy of F Mettler
Badge requirements

- TLD or other device usually placed on upper torso

Courtesy of F Mettler
• 2002 Lundberg (Australia) “Measuring & Minimizing the Radiation Dose to the NMT”*

• Looked at rationale for anterior torso badging. Is it reliable to quantify dose?

• Assumption: uniform beam, incident from front

3 dosimeters on a NMT X 3 months: front collar, front waist, back waist

Recorded dose q 30 min (0730-1800)

Task recorded in journal; alternated injecting RP & scanning; weekly

Limitations: one NMT data
Results

• Uniform beam confirmed: anterior collar & waist readings similar

• **Except:** injection of tracers, collar 70% higher than waist (position of NMT torso for RP injection)

• Collar readings
  – more conservative

Results

• 1/3 of the time, back > front waist readings: likely when NMT back to pt in imaging room or from other source

• **Average doses:**
  • inject: 2 µSv/h/12 µSv/d/3.2 mSv/y
  • scan: 0.2-2 µSv/h/5.4 µSv/d/1.4 mSv/y

RP Preparation/Administration

- Routine handling of RP
- Activity adds to NM dose, esp fingers
- Monitor hand exposure with ring dosimeters:
  - dominant hand, base of ring finger
Badge requirements

- Ring dosimeter usually on 4th finger (dominant hand)
  Film should be facing palm of hand

Courtesy of F Mettler
Hand Exposures

• 2008 Wrzesien et al (Poland) “Hand Exposure to Ionizing Radiation of NM Workers”

• Measured RP finger doses with TLDs

• Reference: 4\textsuperscript{th} ring finger TLD; 5 X lower than thumb, index or middle fingers (RP higher doses than NMT)

• 4\textsuperscript{th} finger TLD may underestimate dose
Hand Exposures

- 2005 Guillet et al (France) “Technologist Radiation Exposure in Routine Clinical Practice with $^{18}$F-FDG PET.”
- FDG > dose but concept important
- Finger dose: 50% dec exposure with monodose c/w multidose vials
- Data also supported: semiautomatic FDG injector & pt video tracking

Syringe Shields
Syringe Shields

• Important to significantly reduce hand exposure in preparing & injecting RP
• Disadvantage: cumbersome

• Hand dose reduction depends on the RP & shield material, but is generally 75 to > 90%
• Tungsten, leaded glass, lead
Patient Transfers

- 2004 Smart et al (Australia) “Task Specific Monitoring of NMT’s Radiation Exposure”
- Constant monitoring of NMT q 32 sec (0830-1700) dose rate in µSv/hr
- Pocket dosimeter at anterior waist
- Procedure journal w/ start & stop times of individual tasks
Activities with the Highest Dose*

1. Transferring incapacitated pt from imaging table to hospital gurney

2. Difficult injections w/o syringe shields

3. Setting pt up for cardiac gated studies

Average Doses

- **Post MDP transfer**: 0.54 µSv (40% of total dose 1.3 µSv)
- **Injecting 24 mCi HDP + tungsten syringe shield**: 0.57 µSv (difficult pt: 1.6 µSv)
- **Setting up pt for gated MIBI**:
  - 1.1 µSv
  - with 0.5 mm Pb apron: 0.6 µSv
  - dec by factor of 2

* Smart et al Rad Protection Dosimetry Vol 109, No 3, Oxford Univ Press, 2004.*
Recommended

1. While waiting for pt transfer, NMT stands away (distance)

2. Use tungsten shield (shielding)

3. Use of a 0.5 mm Pb apron for high activities of Tc$^{99m}$ (shielding)

Question # 4

• Which NM technologist task is generally associated with the highest work-related dose?
  
• A. Radiopharmaceutical preparation
• B. Radiopharmaceutical injection
• C. Patient scanning
• D. Patient transfers
Question # 4

• Which NM technologist task is generally associated with the highest work-related dose?

• A. Radiopharmaceutical preparation
• B. Radiopharmaceutical injection
• C. Patient scanning
• D. Patient transfers
In the final stretch....

....so stand up & stretch!
Patient Imaging

- Injected pt is a significant radiation source
- NM imaging times are extended
- **Rec:** depending on pt condition & imaging protocol, NMT need not remain in room

- Time & Distance tenets (ALARA)
- Average 0.3-3 mrem/procedure to NMT of which **50-90%** can come from imaging*

* Mettler
Scanning Doses: Many Variables

- RP
- Administered activity
- Amount of pt contact, dec with pt requiring no or limited assistance
- Back doses: 30% of front doses
- Procedure type
Variability with Procedure Type

- **Highest:**
  - MUGA > stress MIBI & Bone scans

- **Lowest:**
  - Thyroid, thallium cardiac
  - Post $^{131}$I WBS low with “distance”
Higher Dose Procedures

• MUGA/cardiac:
  – high administered activities
  – pt contact during “set up” time

• Bone scans:
  – potentially high dose with inc pt contact
  – limited contact once pt is on the imaging table
Question # 5

• Which NM procedure is generally associated with the highest NM technologist occupational dose?
  
• A. Bone SPECT
• B. MUGA
• C. $^{131}\text{I}$ post therapy scan
• D. Stress Tc$^{99m}$ MIBI
Question # 5

• Which NM procedure is generally associated with the highest NM technologist occupational dose?

• A. Bone SPECT
• B. MUGA
FDG vs General NM Exposure

- 2 yr prospective study
- PET/NM (quarterly): 771 & 524 µSv
- Estimated PET proced dose: 4.1 µSv
- FDG IV (w/o & w/ 1° shield): 2.5→1.4 µSv
- Trolley-mounted 2° shield: 3.6→1.9 µSv

PET NMT Task & Scheduling*

- PET/CT: 8-10 studies/day
- 2 technologists: weekly rotation of FDG injection and scanning to include pt transfers
- Q 3 month rotation (preferably per yr)

* Teaching site in San Antonio, Texas
PET NMT Tasks

• **Injection:**
  - **Time:** < 30 sec (IV running before)
    explain procedure to pt before inject FDG & answer questions
  - **Distance:** close to pt & FDG
  - **Shielding:** PET syringe shield in a shielded carrier in shielded room
PET NMT Tasks

• **Scanning/Pt transfer:**
  - **Time:** 1-2 min (pt w/o assistance); scanner is in adjacent room; brief re-explanation, pt on & off table, position pt
  - **Distance:** close
  - **Shielding:** Pb glass in scanner control room
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NMT PET exposures

- **2009** (quarterly rotation of 2 NMT)
  - Ring dose >> body dose (factor 2-4)
  - Ring: 636/483 mrem (2 outliers)
  - Body: 149/142 mrem

- **2010** (2 quarters)
  - Ring dose twice body dose
  - Ring 151 mrem; Body 78 mrem
NMT PET exposures

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  - Ring dose >> body dose (factor 2-4)
  - Ring: 636/483 mrem (2 outliers)
  - Body: 149/142 mrem

- **2010** (2 quarters); NMT education!
  - Ring dose twice body dose
  - Ring 151 mrem; Body 78 mrem
Summary

• Inc medical imaging using ionizing radiation, CT, NM, VIR (1980)

• Concern for latent effects of radiation (CA induction, genetic effects): medical, epidemiological, economic
Summary

• Inc NM procedures, inc occupational exposure (NMT)
• NRC limits & ALARA, can help reduce & minimize work-related exposure
• Strict adherence: time, distance, shielding
• Monitoring: wear badges