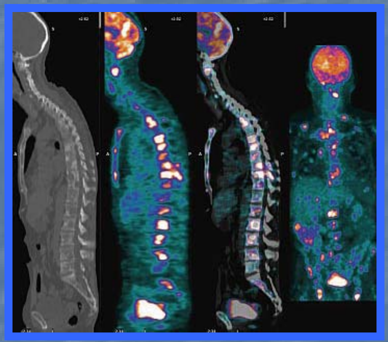
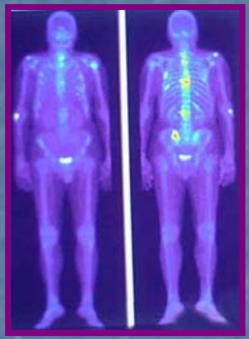
Memorial Sloan-Kettering Cancer Center
The Best Cancer Care. Anywhere.

Patient Safety Concerns in Diagnostic Radiology?





Lawrence T. Dauer, PhD, CHP
Assistant Attending Health Physicist
Department of Medical Physics

RAMPS/GNYCHPS Spring Symposium – April 30, 2010

Radiation Dose Associated With Common Computed Tomography Examinations and the Associated Lifetime Attributable Risk of Cancer

Arch Intern Med. 2009;169(22):2078-2086

Rebecca Smith-Bindman, MD; Jafi Lipson, MD; Ralph Marcus, BA; Kwang-Pyo Kim, PhD; Mahadevappa Mahesh, MS, PhD; Robert Gould, ScD; Amy Berrington de González, DPhil; Diana L. Miglioretti, PhD

Projected Cancer Risks From Computed Tomographic Scans Performed in the United States in 2007

Arch Intern Med. 2009;169(22):2071-2077

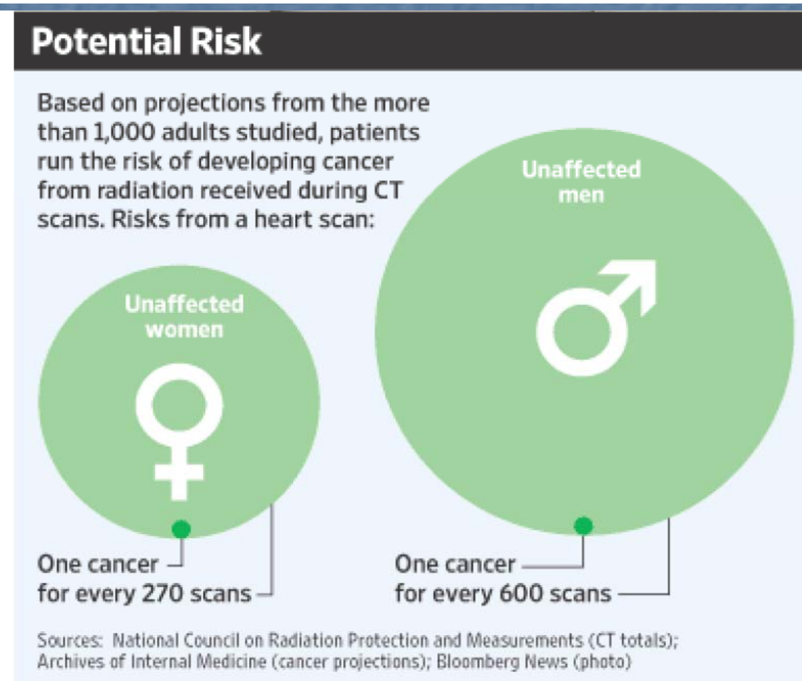
Amy Berrington de González, DPhil; Mahadevappa Mahesh, MS, PhD; Kwang-Pyo Kim, PhD; Mythreyi Bhargavan, PhD; Rebecca Lewis, MPH; Fred Mettler, MD; Charles Land, PhD

THE WALL STREET JOURNAL.
WSJ.com

U.S. NEWS | DECEMBER 15, 2009

CT Scans Linked to Cancer

Study Warns Radiation Dose From Single Test Can Trigger Disease in Some People

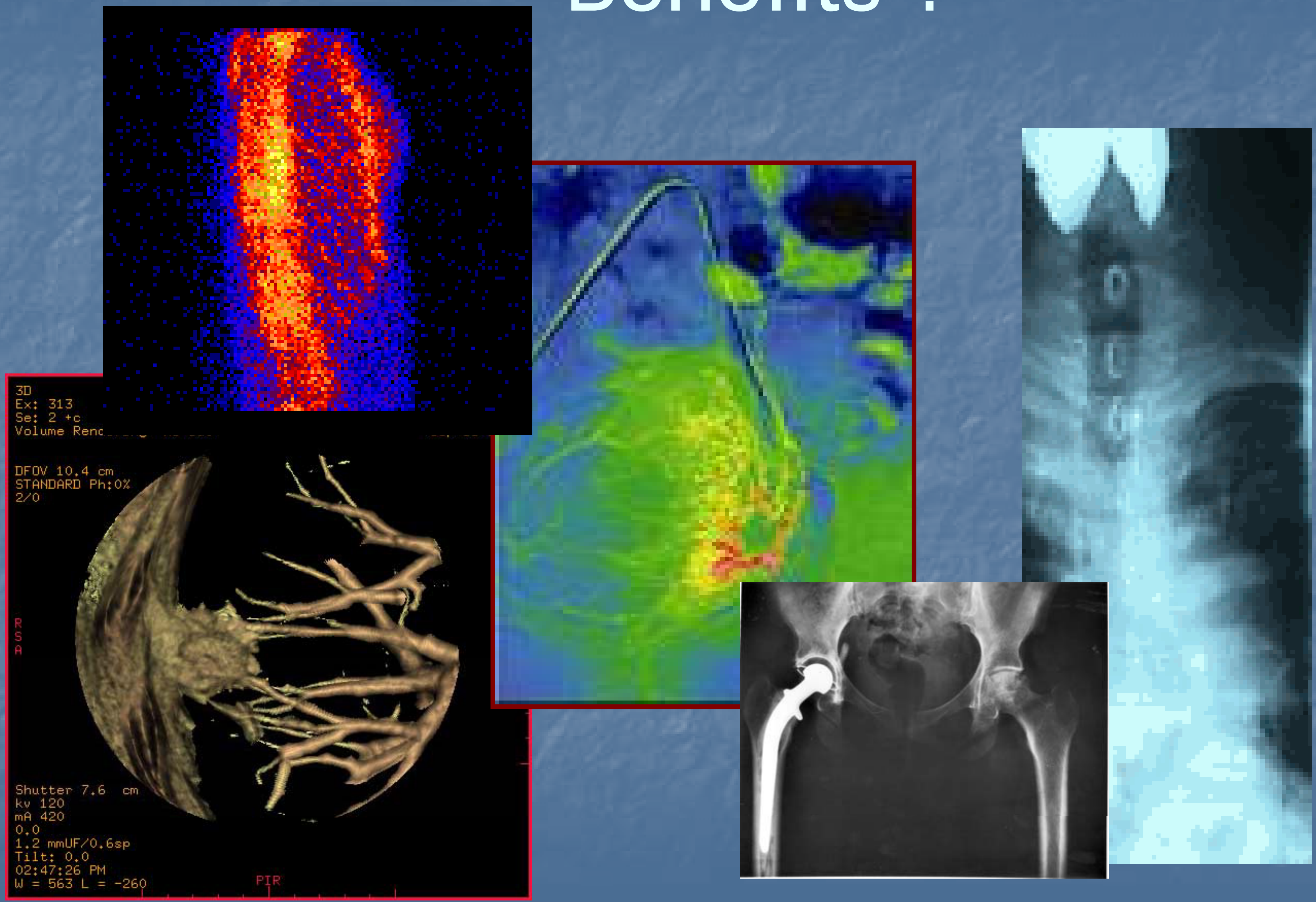


msnbc.com

15,000 will die from CT scans done in 1 year

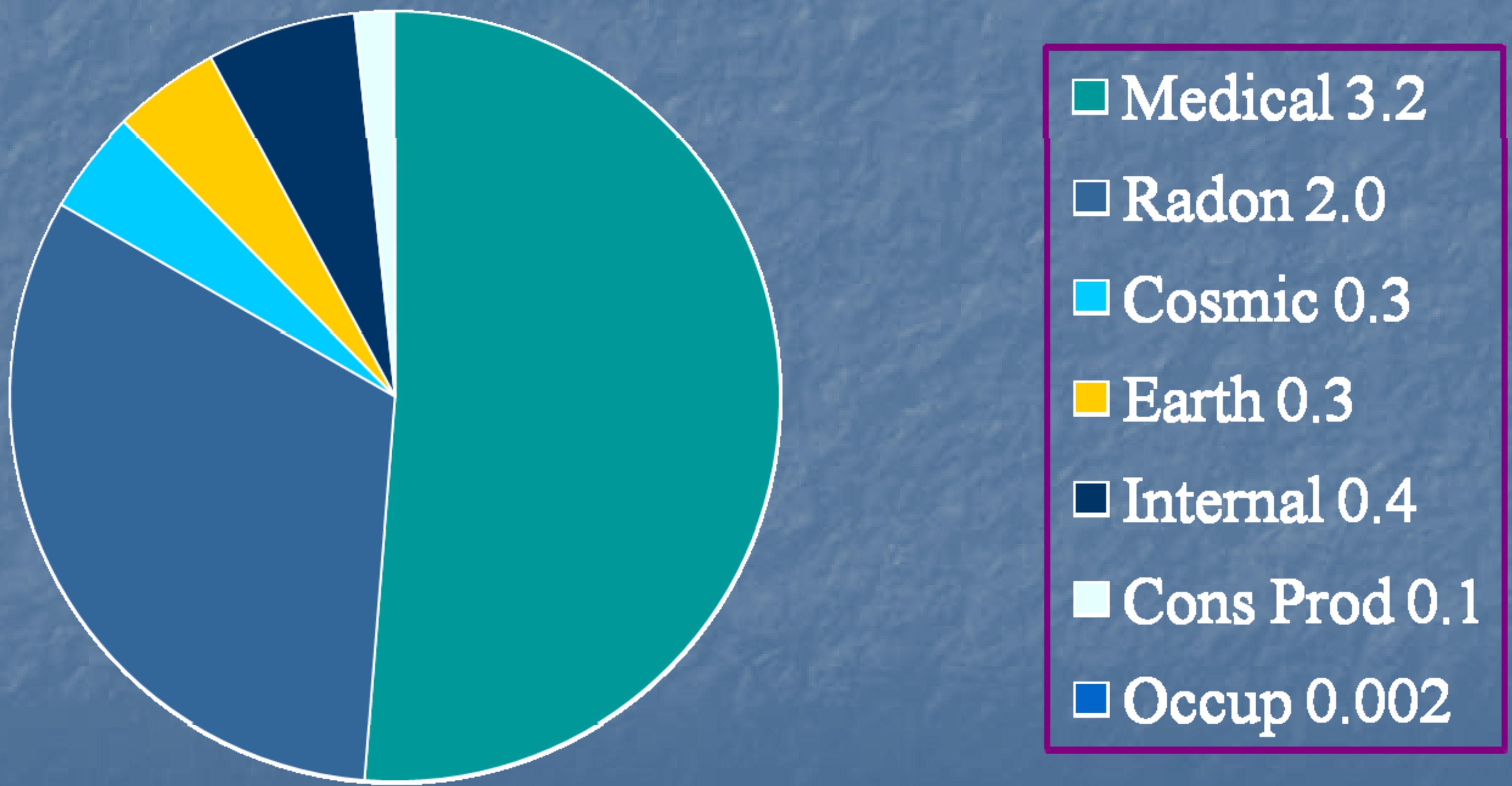
Scans have higher levels of radiation than thought, researchers say

Benefits ?


3D
Ex: 313
Se: 2 +c
Volume Renc
DFOV 10.4 cm
STANDARD Ph:0%
2/0
R
S
A
Shutter 7.6 cm
kv 120
mA 420
0.0
1.2 mmUF/0.6sp
Tilt: 0.0
02:47:26 PM
W = 563 L = -260
PIR

Background Radiation in U.S.

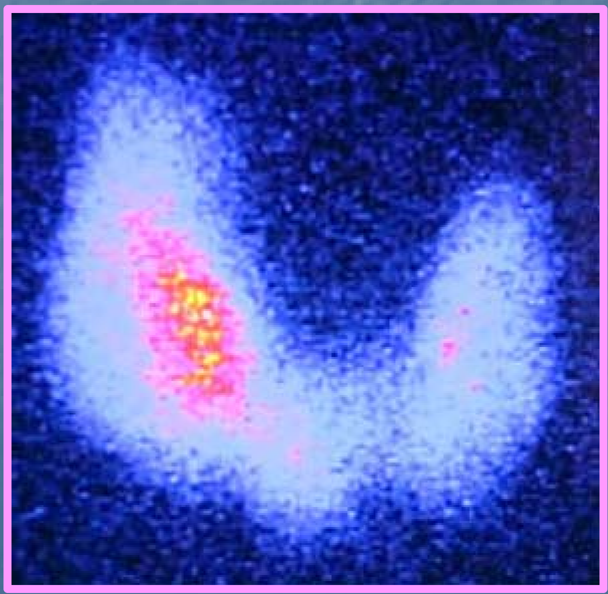
~6.3 mSv/yr
~0.02 mSv/day
(~2 mrem/day)



NCRP

Absorbed Dose

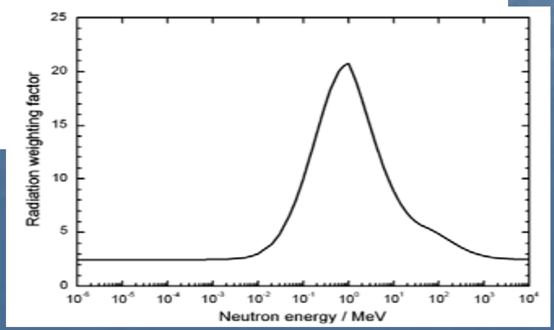
$$D = \frac{\mathrm{d}\bar{\varepsilon}}{\mathrm{d}m}$$



Equivalent Dose

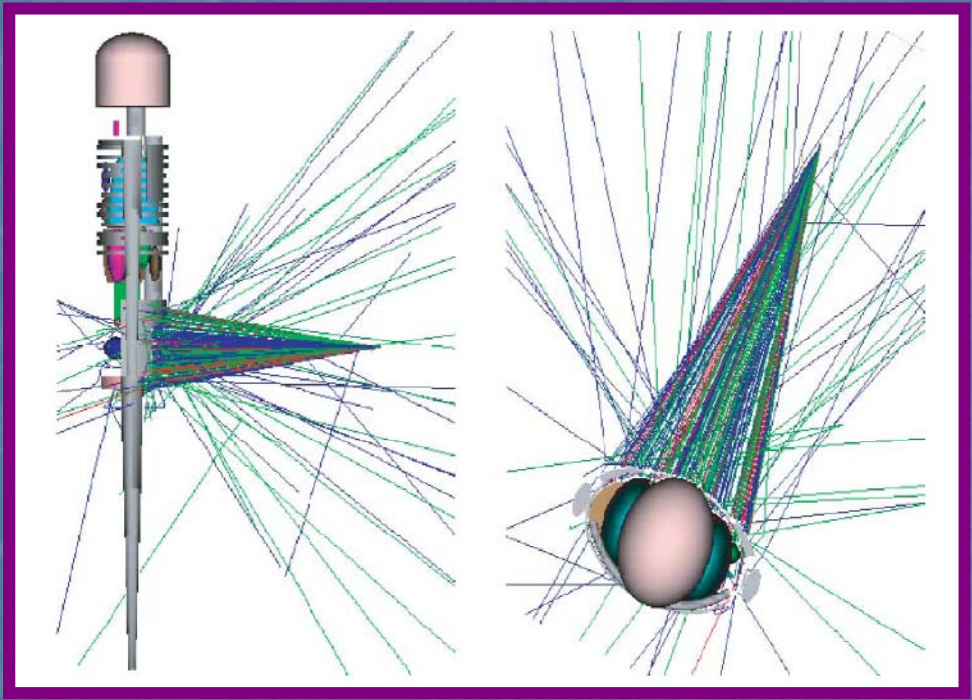
$$H_{\mathrm{T}} = \sum_{\mathrm{R}} w_{\mathrm{R}} D_{\mathrm{T,R}}$$

Radiation type	Radiation weighting factor, w_{R}
Photons	1
Electrons[a] and muons	1
Protons and charged pions	2
Alpha particles, fission fragments, heavy ions	20
Neutrons	



Risk Evaluations

- Monte-Carlo transport and energy deposition
- Equivalent Dose
- Age-Adjusted
- Gender-Adjusted
- Organ risk factors



Effective Dose

$$E = \sum_T w_T H_T = \sum_T w_T \sum_R w_R D_{T,R}$$

Tissue	w_T	$\sum w_T$
Bone-marrow (red), Colon, Lung, Stomach, Breast, Remainder tissues*	0.12	0.72
Gonads	0.08	0.08
Bladder, Oesophagus, Liver, Thyroid	0.04	0.16
Bone surface, Brain, Salivary glands, Skin	0.01	0.04
	Total	1.00

* Remainder tissues: Adrenals, Extrathoracic (ET) region, Gall bladder, Heart, Kidneys, Lymphatic nodes, Muscle, Oral mucosa, Pancreas, Prostate (♂), Small intestine, Spleen, Thymus, Uterus/cervix (♀).

ICRP-103 (2007)

Internal Radionuclide Radiation Dosimetry

MIRD Formalism

(Medical Internal Radionuclide Dosimetry)

Absorbed fractions and S factors from reference anatomic phantoms

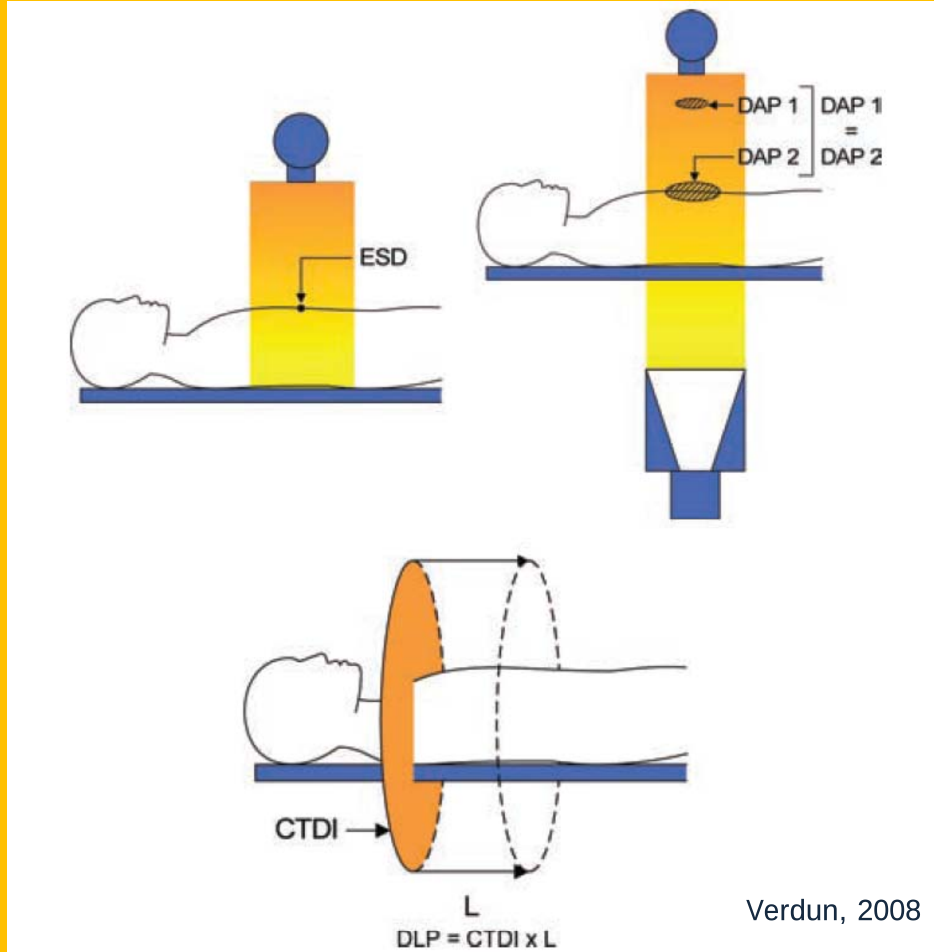
$$D(r_k \leftarrow r_h) = \frac{\tilde{A}_h \sum_i \Delta_i \, \phi_i(r_k \leftarrow r_h)}{M_k}$$

$S(r_k \leftarrow r_h)$

- $\tilde{A}_h$: Number of decays in Source Region r_h — *Cumulated Activity*
- Δ_i: Energy Emitted per Decay — *Equilibrium Dose Constant*
- $\phi_i(r_k \leftarrow r_h)$: Fraction of energy emitted in Source Region r_h absorbed in Target Region r_k — *Absorbed Fraction*
- M_k: Mass of Target Region r_k
- $D(r_k \leftarrow r_h)$: Absorbed Dose from Source Region r_h to Target Region r_k

Doses in CT

- ESD
- CTDI
- DLP = CTDI x L
- E/DLP for adults:
  - Head 0.0023
  - Neck 0.0054
  - Chest 0.017
  - Abd 0.015
  - Pelv 0.019



Verdun, 2008

ACR, 2004

Diagnostic CT Scans: Assessment of Patient, Physician, and Radiologist Awareness of Radiation Dose and Possible Risks[1]

Christoph I. Lee, AB
Andrew H. Haims, MD
Edward P. Monico, MD
James A. Brink, MD
Howard P. Forman, MD, MBA

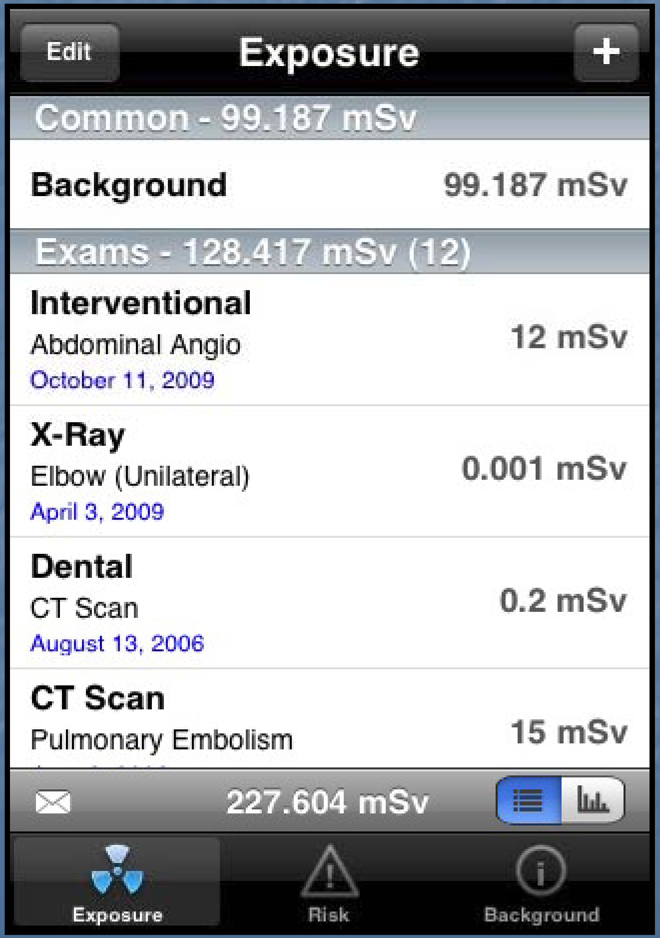
Index terms:
Computed tomography (CT), radiation exposure
Radiations, exposure to patients and personnel

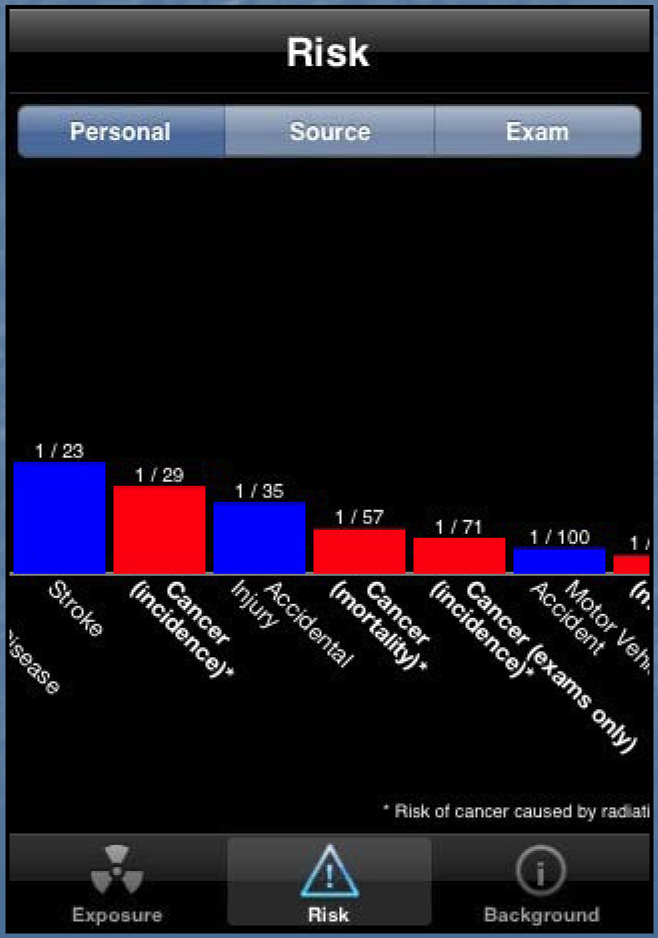
Published online before print
10.1148/radiol.2312030767
Radiology 2004; 231:393–398

TABLE 3
Dose Estimates for One CT Scan versus One Chest Radiograph

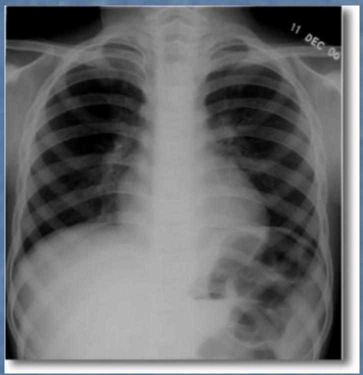
Respondent Group	CT ≤ CR	CT > CR < 10 × CR	CT ≥ 10 × CR < 100 × CR	CT = 100–250 × CR	CT ≥ 500 × CR

Radiation Passport 1.0 iPhone application





Typical Radiation Doses - General Radiology



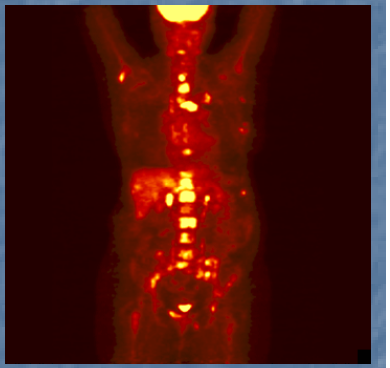
Examination	Effective Dose mSv
Dental	0.05 (0.02-0.09)
Chest	0.1 (0.02-0.81)
Head	0.1 (0.1-0.22)
Mammography	0.7 (1-3 gland)
Abdomen/Pelvis	1.2 (0.7-1.2)

See http://mskweb5.mskcc.org/intranet/html/65927.cfm
For a complete listing of typical radiology doses

Typical Radiation Doses - Computed Tomography

Examination	Effective Dose mSv
PET Attenuation (CT Only)	0.72
Head	2 (0.8-5)
Chest	7 (4.6-20.5)
Abdomen or Pelvis	10 (6-27.4)
CT Angiography	13 (4.6-15.8)

Typical Radiation Doses - Nuclear Medicine

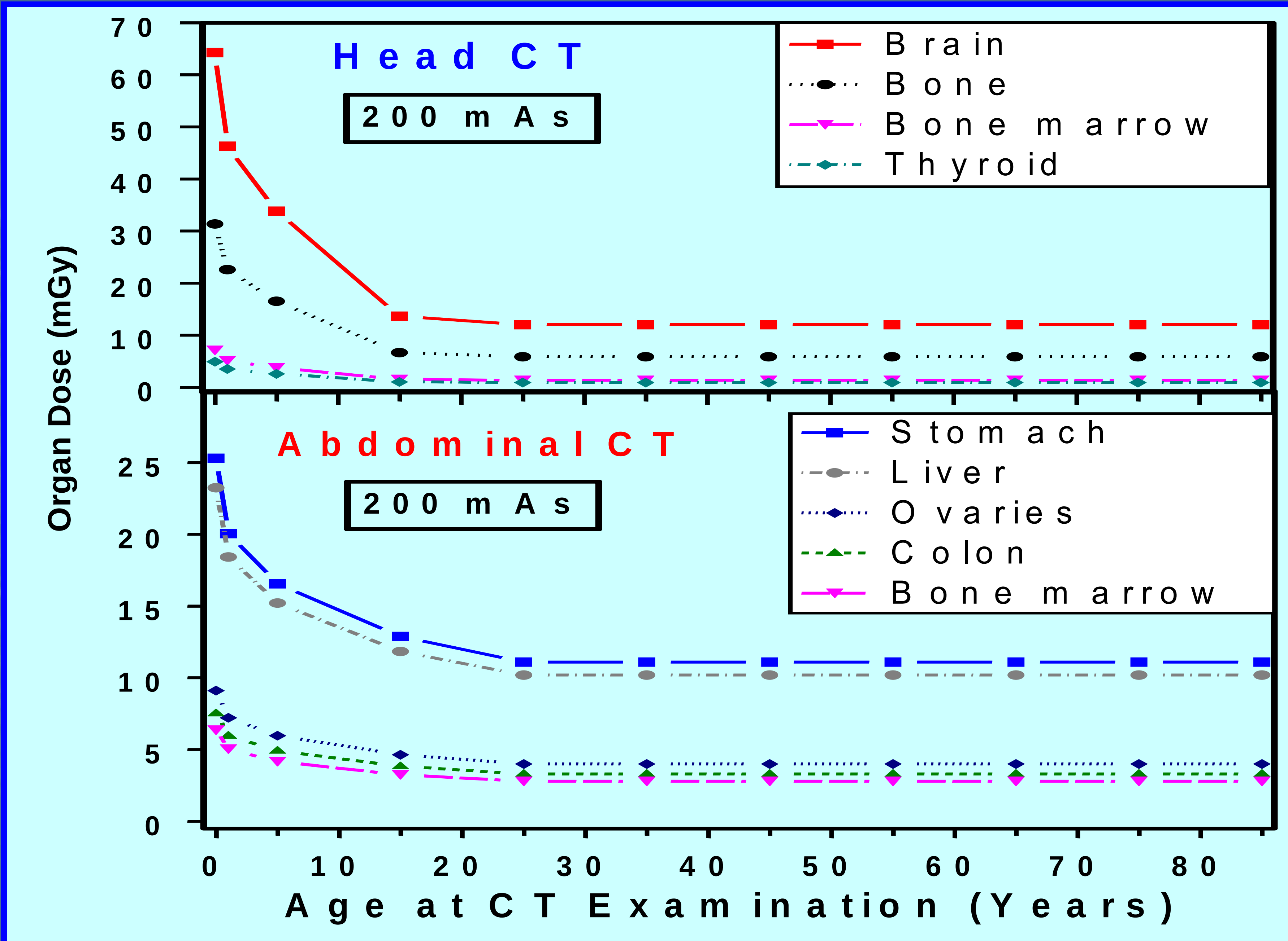


Examination	Effective Dose mSv
F-18 FDG 15mCi (Nuclear Med only)	9
I-131 MIBG 1mCi	7.5
Tc-99m pertech.	5
Tc-99m stress	6
I-131 therapy	270

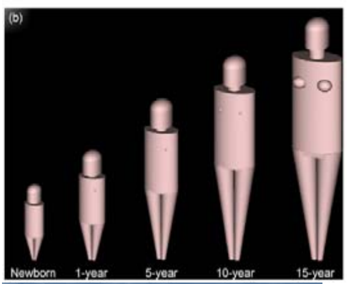
Typical Radiation Doses
Fluoroscopy Entrance Skin Dose

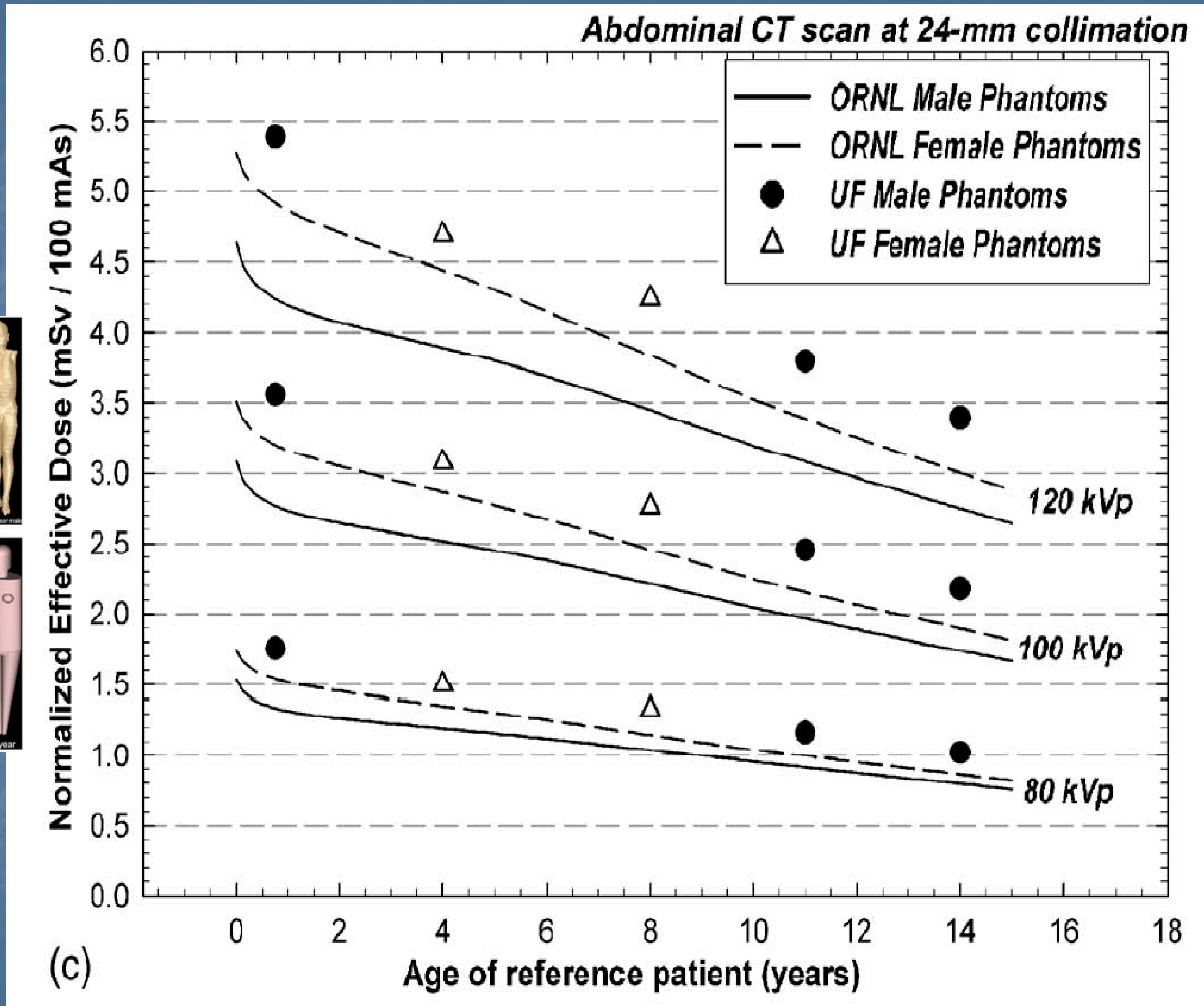
Dauer,
Thornton...
JVIR 2009

Examination	Skin Dose mGy
Hepatic Embolization	2000 (1251-9500)
Arterial Embolization	3000 (1761-8073) ED~60 mSv
Biliary Drainage	660 (401-3569)
IVC Filter	260 (162-2686)
Mediport – Chest	12 (8-620)



*Adapted from Brenner *et al*. 2001

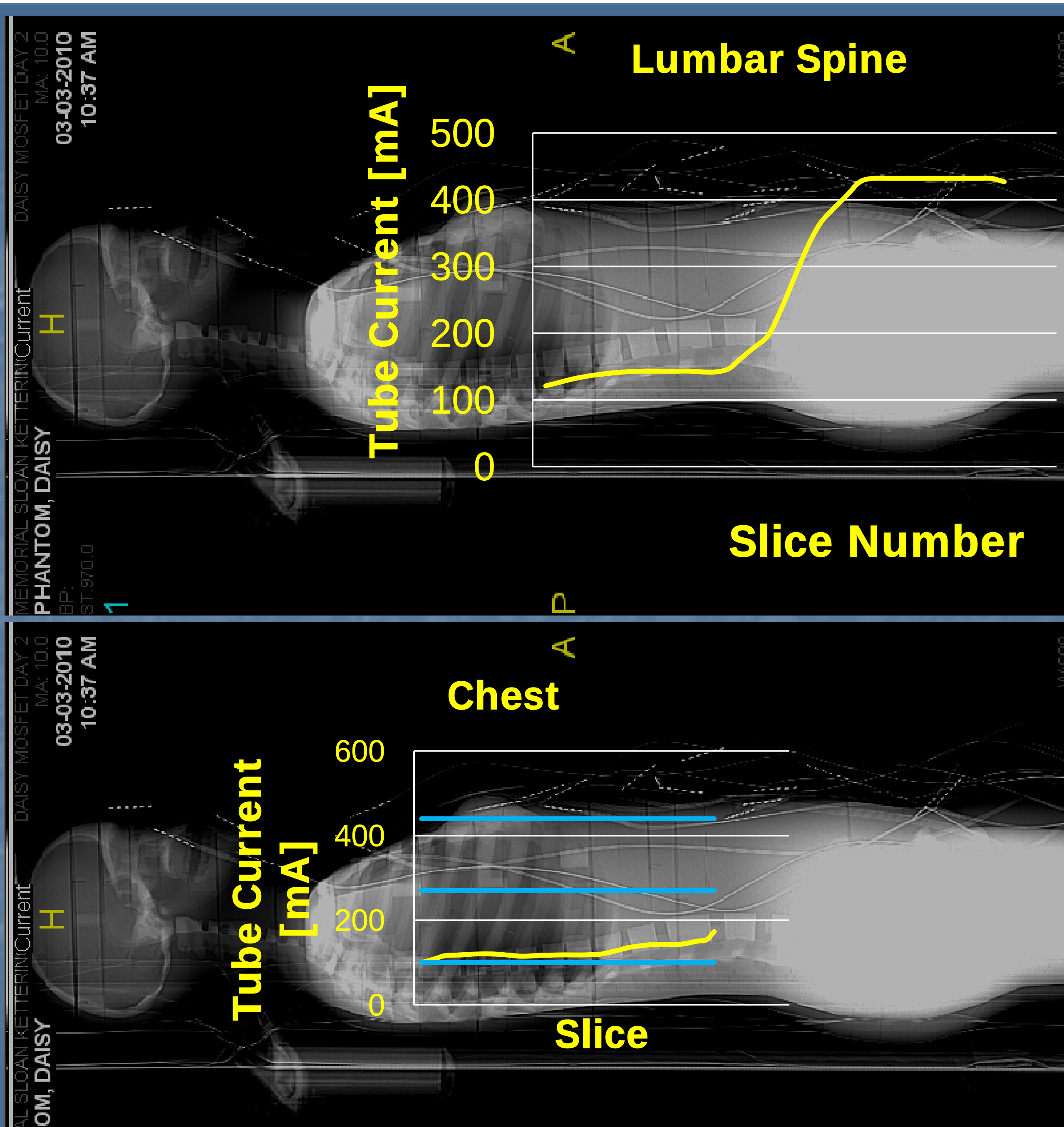


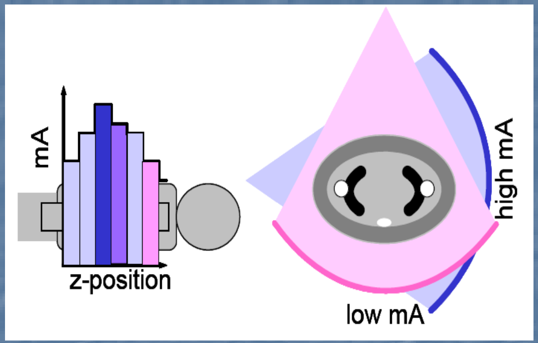


Lee, 2007,MedPhys


One size does not fit all...
There's no question – CT helps us save kids' lives!
But...When we image, radiation matters!
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 the kVp and mA
• One scan (single phase) is often enough
• Scan only the indicated area
A timely message from the Alliance for Radiation Safety in Pediatric Imaging.
image gently℠
Visit www.imagegently.org.
Made possible by an unrestricted educational grant from GE Healthcare.
The Alliance for Radiation Safety in Pediatric Imaging is:
The Society for Pediatric Radiology - American Association of Physicists in Medicine - American College of Radiology - American Society of Radiologic Technologists - American Academy of Pediatrics - American Osteopathic College of Radiology - American Registry of Radiologic Technologists
American Roentgen Ray Society - Association of University Radiologists - Conference of Radiation Control Program Directors - National Council on Radiation Protection - Radiological Society of North America - Society of Computed Body Tomography and Magnetic Resonance

Auto Exposure control





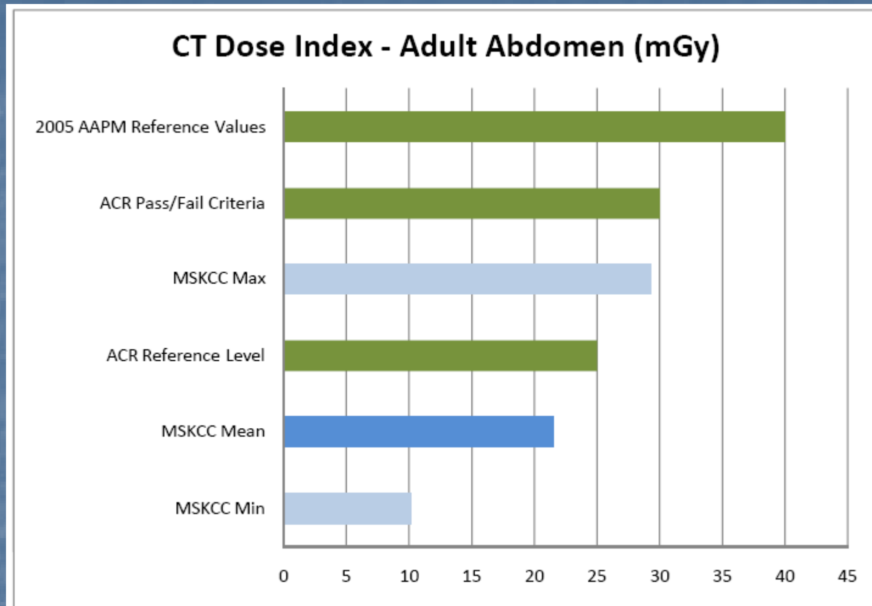
Classification: Unclassified

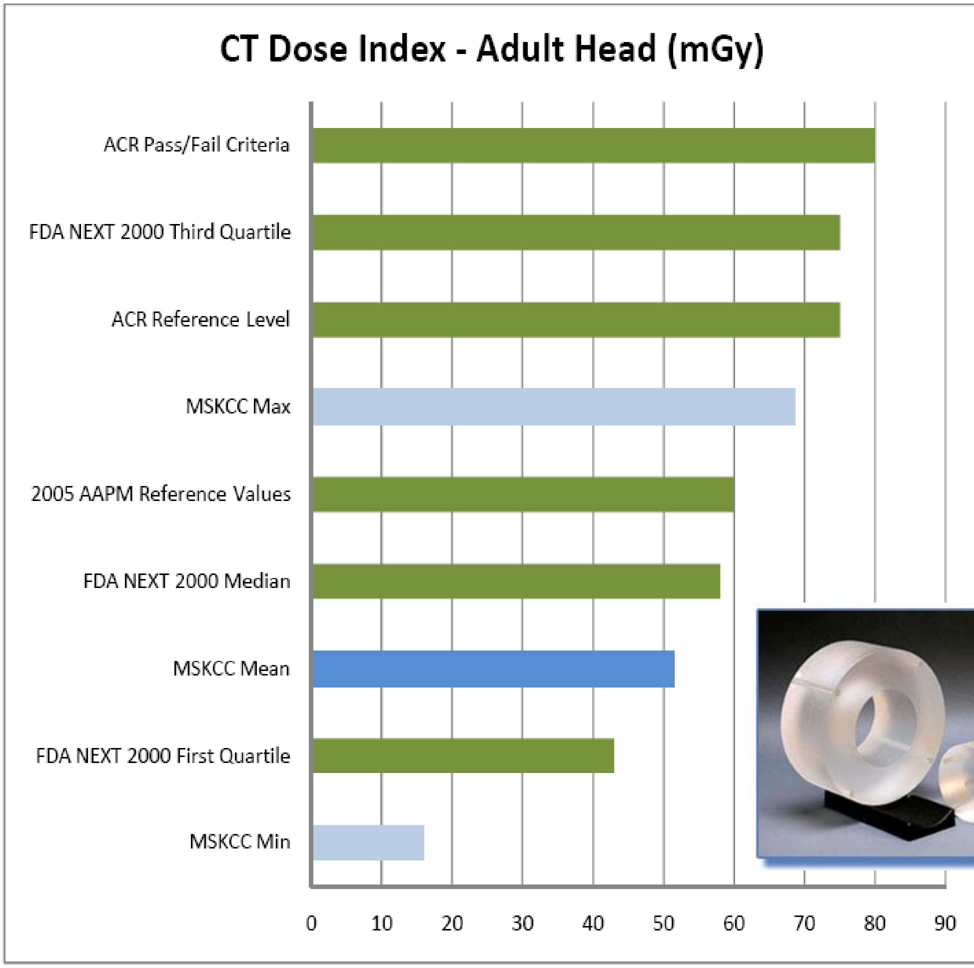
How do we assure quality control on an ongoing basis?

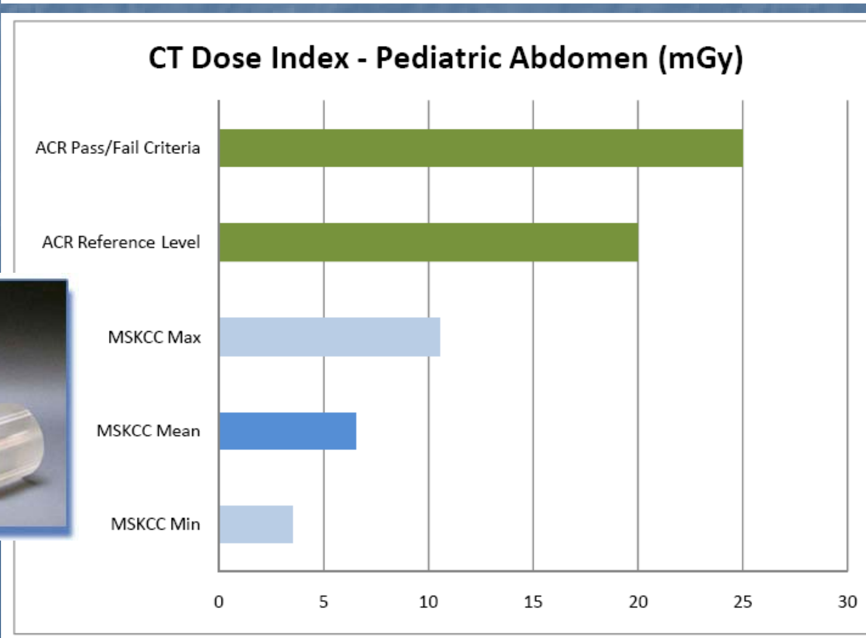
- Medical Physicist verifies CT dose on new equipment prior to 1st patient use, at least 1x per year and at x-ray tube changes.
- CT dose measurements meet American College of Radiology, State, and Local guidelines for dose.
- CT machine settings are developed by Radiologists and Radiology specialists.
- Technique Charts showing machine settings and standard delivered doses are posted at each CT.

Quality Control - Standard ACR Phantoms

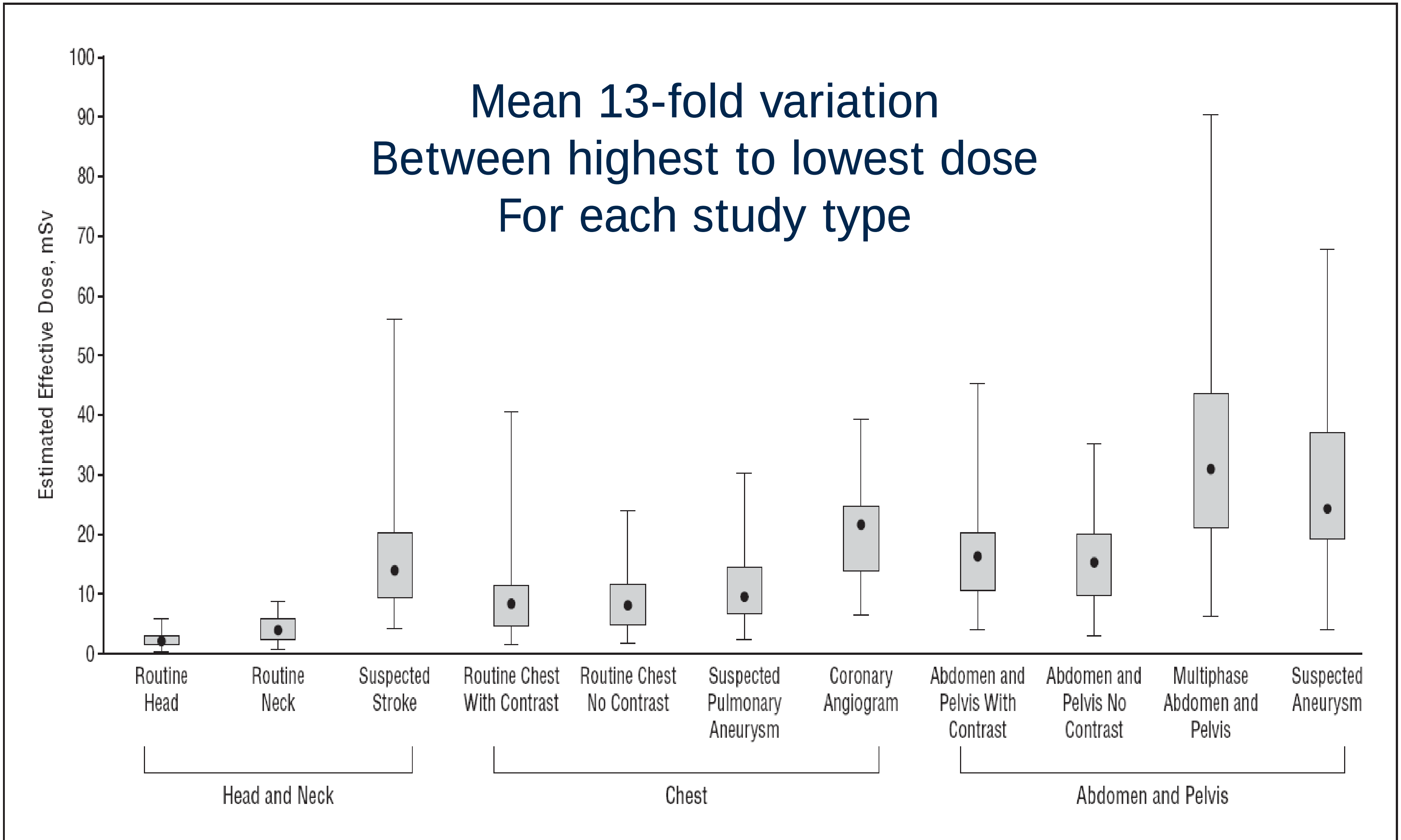
Erdi, 2010 - MSKCC data







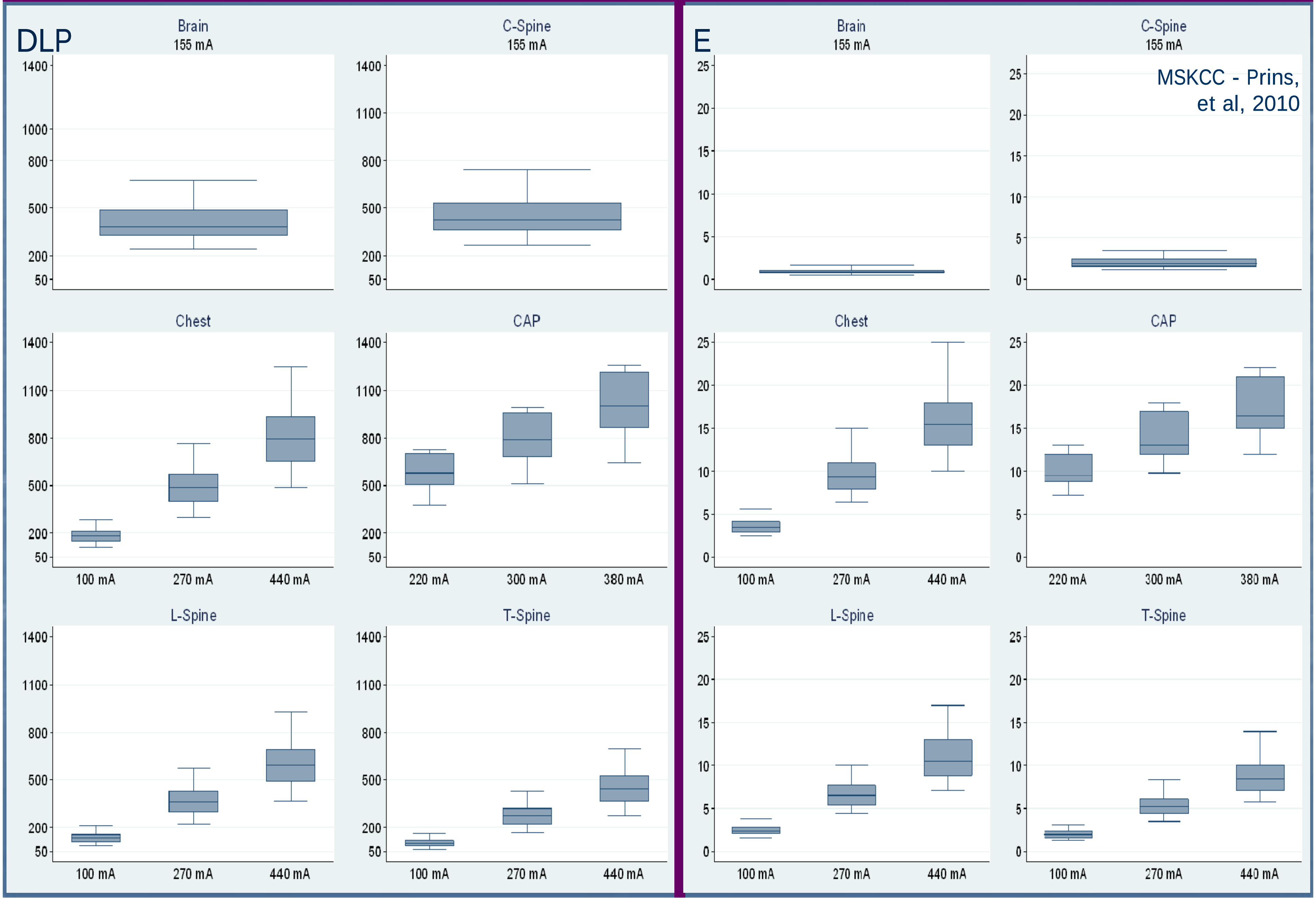
Variability in CT doses for real individuals



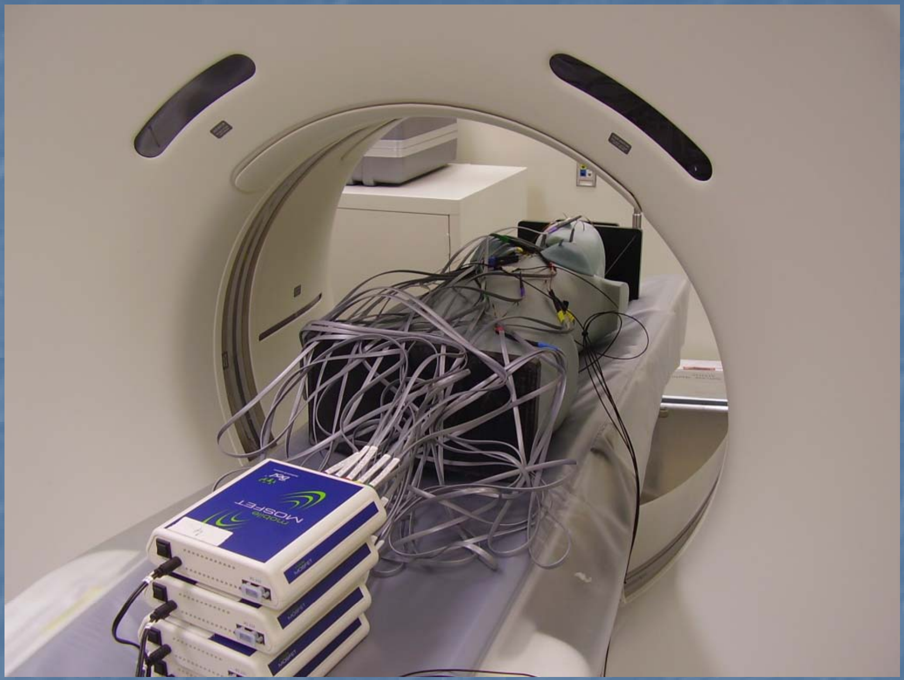
Arch Intern Med. 2009;169(22):2078-2086

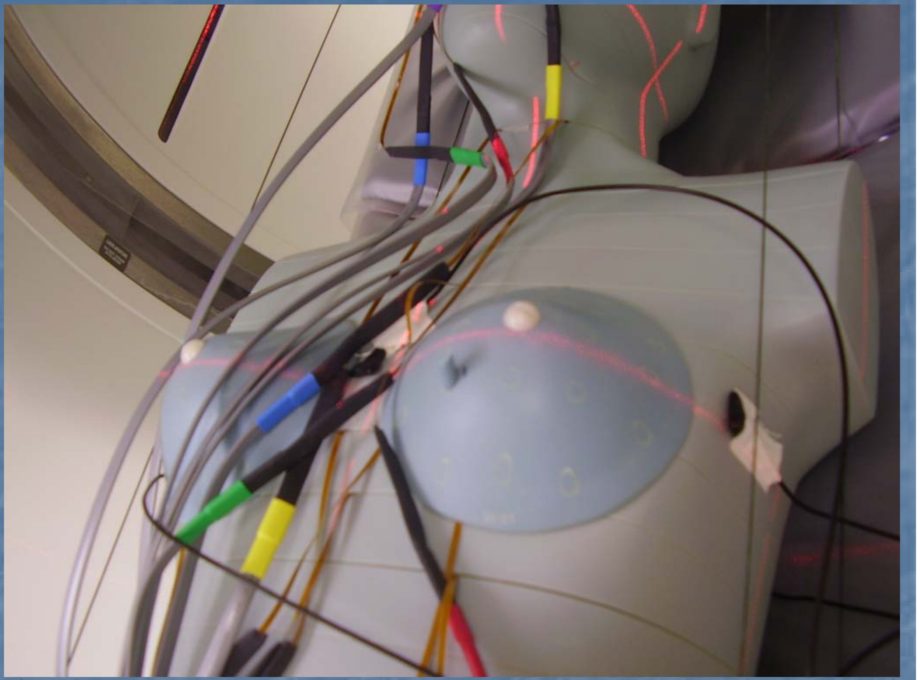
Rebecca Smith-Bindman, MD; Jafi Lipson, MD; Ralph Marcus, BA; Kwang-Pyo Kim, PhD; Mahadevappa Mahesh, MS, PhD; Robert Gould, ScD; Amy Berrington de González, DPhil; Diana L. Miglioretti, PhD

Machine Model & Type = 2.5 to 5-fold variation



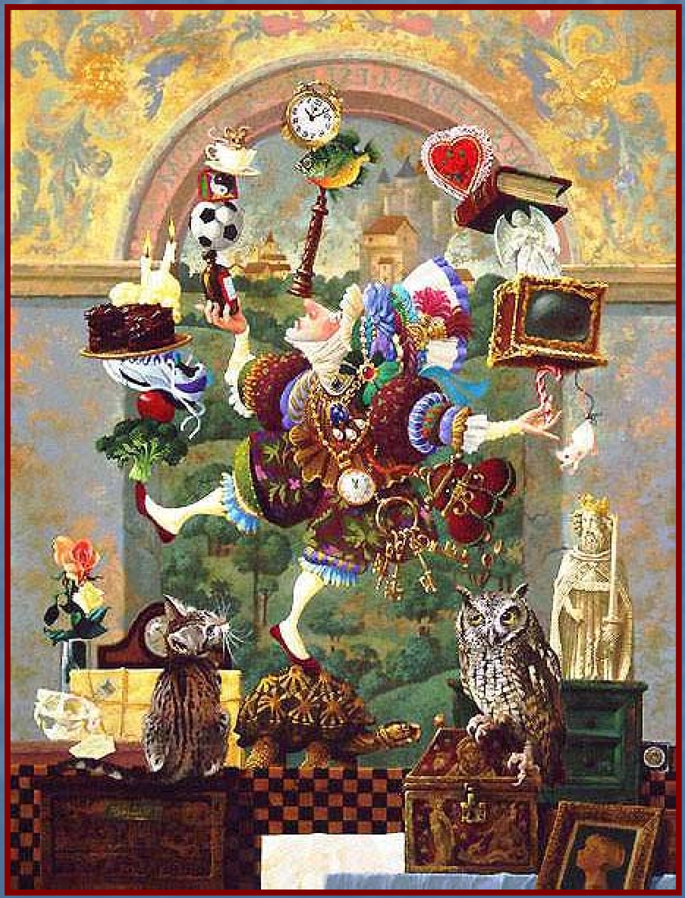
Ongoing Evaluations

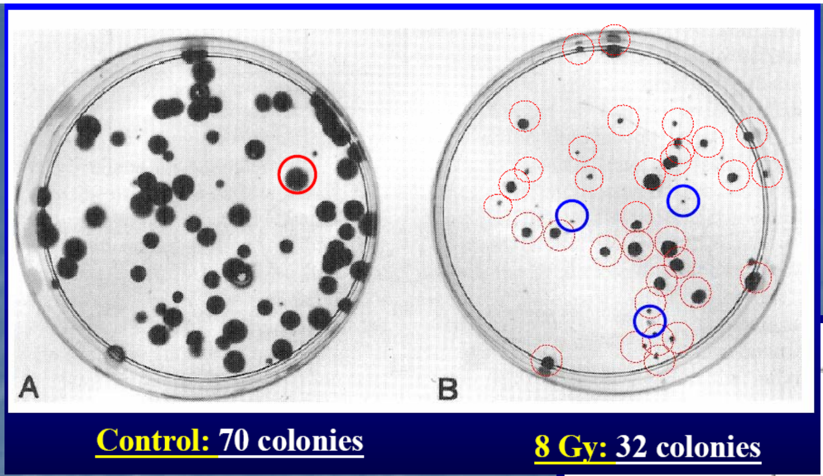


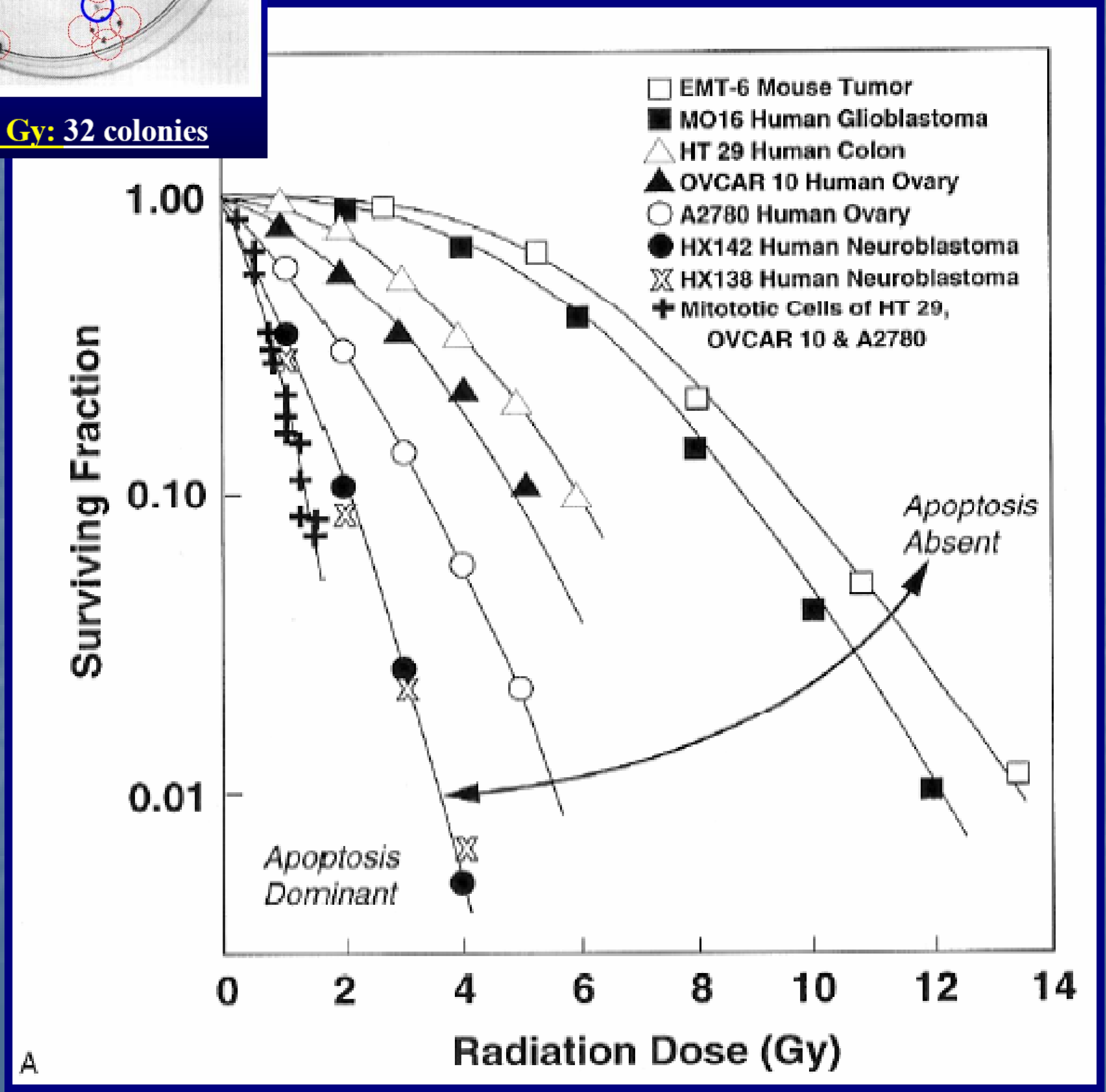


Principles of Radiation Safety in Radiology

- Justification
  - Benefit greater than risk
- Optimization
  - Benefit AHARA
  - Risk ALARA
- Limitation
  - Occupational doses based on risk of safe industries

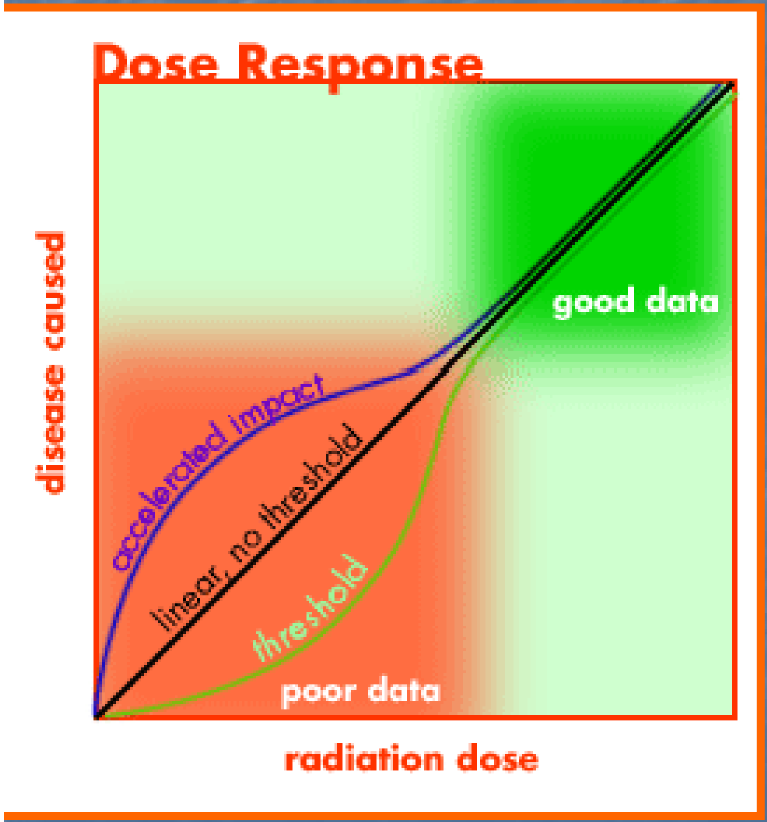


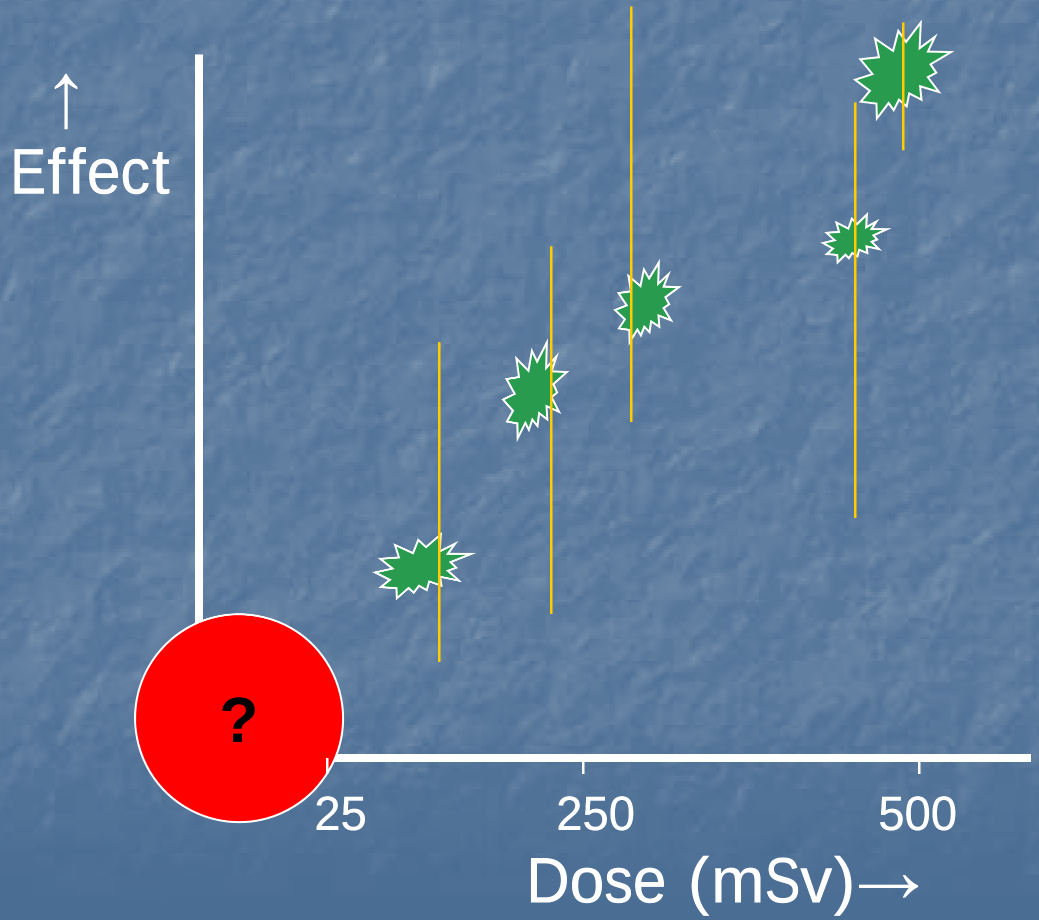

A
B
Control: 70 colonies
8 Gy: 32 colonies


EMT-6 Mouse Tumor
MO16 Human Glioblastoma
HT 29 Human Colon
OVCAR 10 Human Ovary
A2780 Human Ovary
HX142 Human Neuroblastoma
HX138 Human Neuroblastoma
Mitototic Cells of HT 29, OVCAR 10 & A2780
Surviving Fraction
1.00
0.10
0.01
Apoptosis Absent
Apoptosis Dominant
0
2
4
6
8
10
12
14
Radiation Dose (Gy)
A

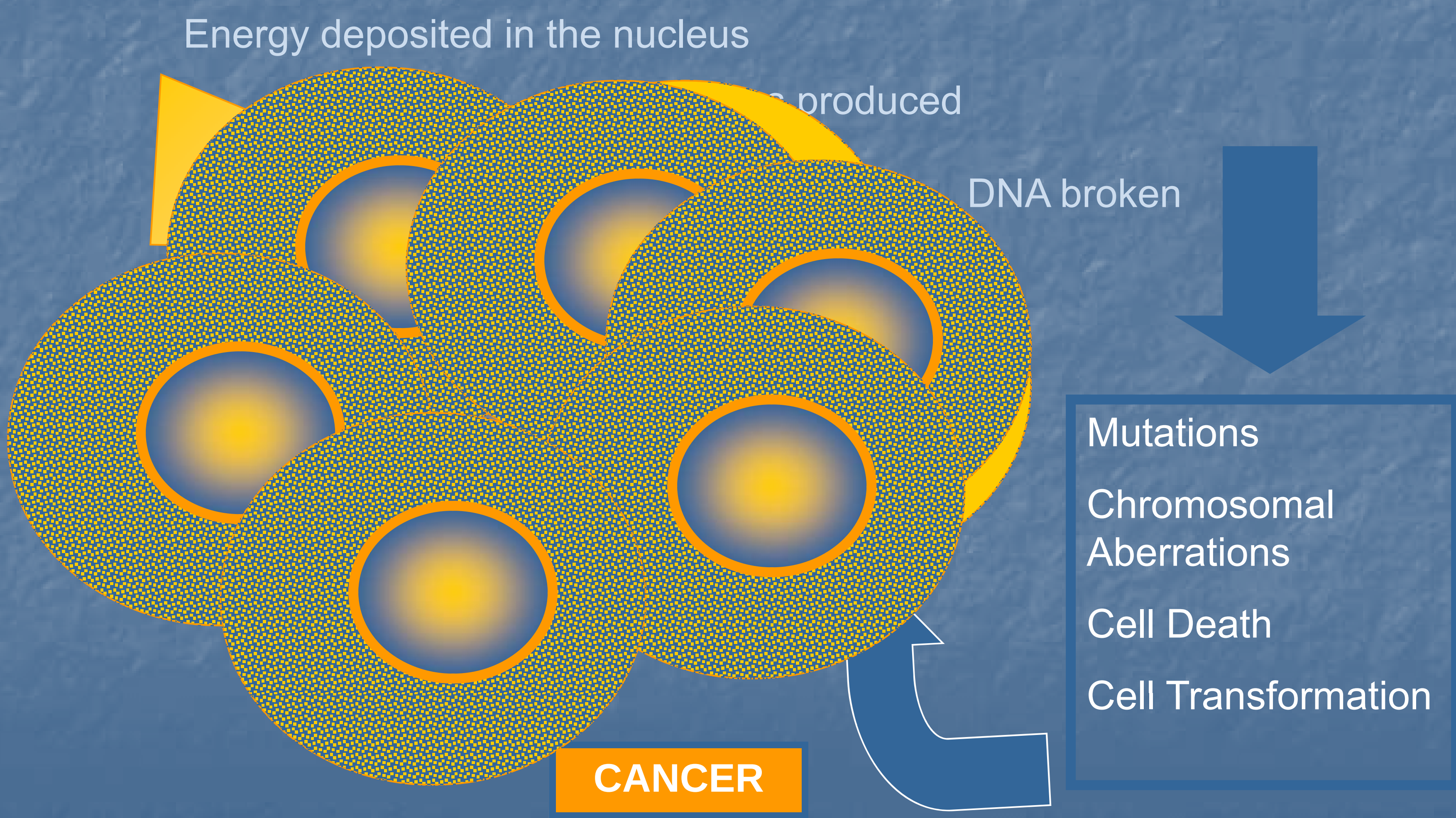
Can We Predict Effects at Low Doses?

While moderate/high doses cause well-documented effects, we cannot measure significant effects at the doses where typical diagnostic or regulated doses occur.

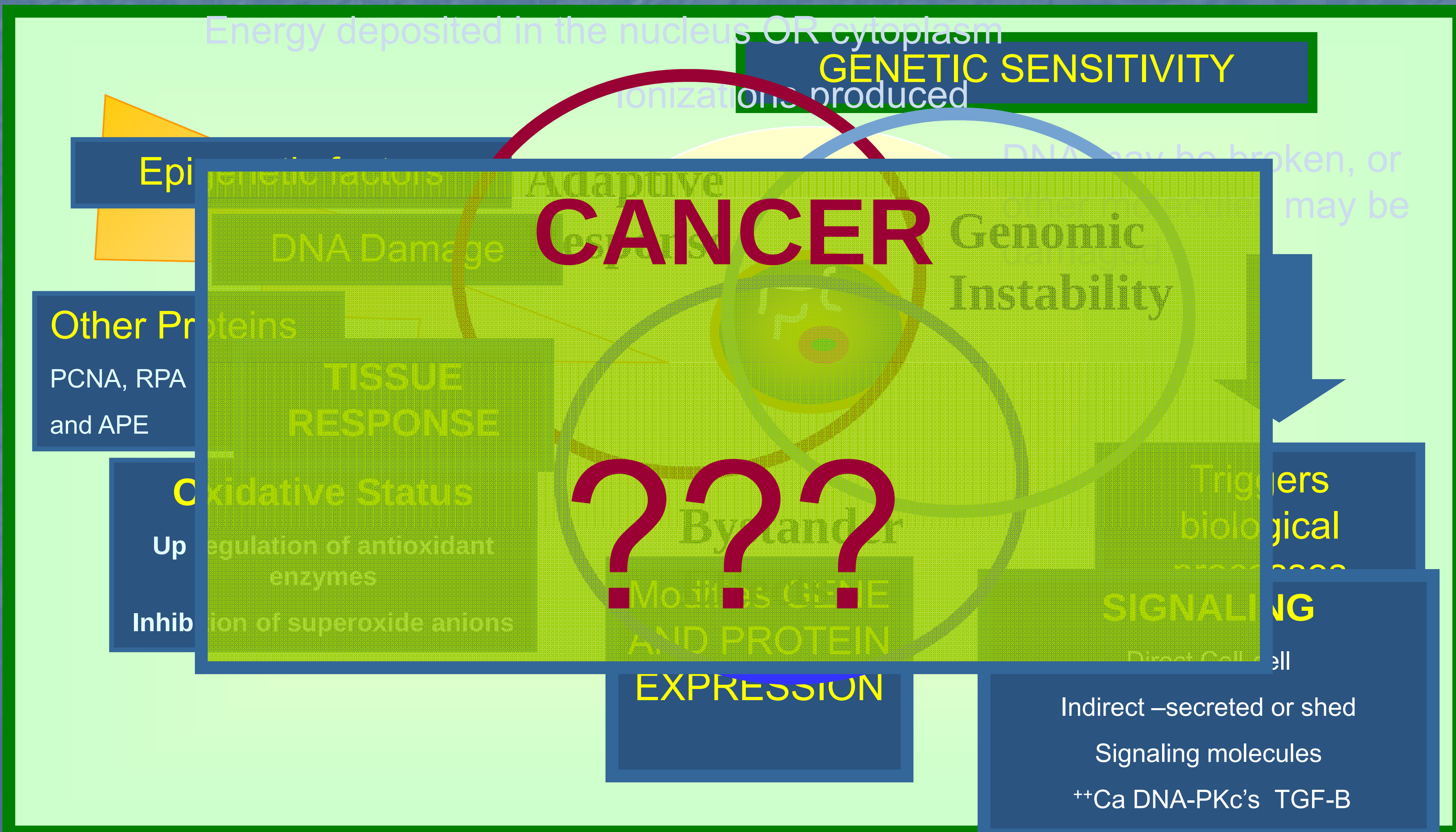




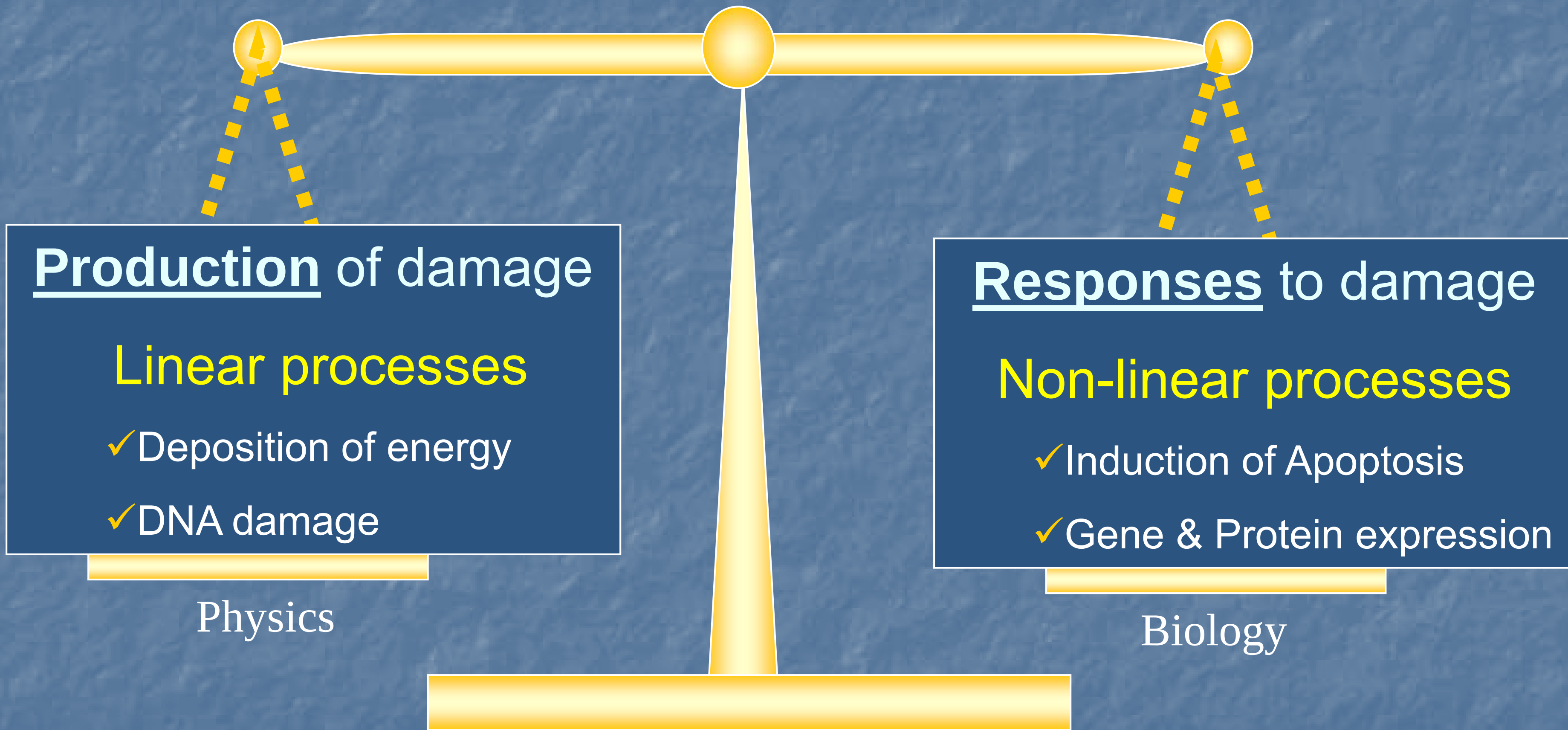
Classic Risk Paradigm



Expanded Risk Paradigm



Need an Expanded Paradigm for Low-Dose Response



Evaluation Conclusions Vary

- BEIR VII - NAS
  - Available biological and biophysical data supports a linear-no-threshold (LNT) risk model.
- ICRP 99/103
  - While existence of a low dose threshold may be likely for radiation related cancers in some tissues, the evidence does not support a universal threshold. DDREF-modified LNT suggested as prudent.
- French Academy
  - New radiobiology focus. Biological differences at high vs. low doses. LNT overestimates risk at low doses.

Low Dose - Linear Risk Model (~5% per Sv)

ICRP-103 for cancer and heredity effects

Exposed Population	Cancer	Heredity Effects	Total
Whole	5.5	0.2	5.7
Adult	4.1	0.1	4.2

A statistically significant increase in cancer has not been detected in populations exposed as adults to doses of less than 50 mSv.

No hereditary effects in atomic bomb survivor offspring.

~ Patient Risks

Risk of contracting cancer increased by less than ½%	50 mSv
Temporary Sterilization (Men)	150 mGy
Temporary blood count change	250 mSv
Cataract	<1000 mGy
Permanent Sterilization (Women)	2500 mGy
Skin Erythema (reddening)	3000 mGy

Fetal Radiation Risk

- Most Risk – 1st Trimester
- No Malformations <100mGy
- No Malformations 100-1000mGy 3rd Trimester
- Termination of pregnancy at <50 mGy is NOT justified based upon radiation risk
- Take care - especially during multiple pelvic CTs, long fluoro, or radiotherapy

Wagner, ICRP, IAEA, ACOG

Most risk

Less

Least

ICRP-103 on Individual Risks

"it remains the policy of the Commission that its recommended nominal risk coefficients should be applied to whole populations and <u>not to individuals</u>...[and] believes that this policy provides for a general system of protection that is simple and sufficiently robust" (p.55)

RADIATION RISK IN PERSPECTIVE

HEALTH PHYSICS SOCIETY

POSITION STATEMENT OF THE HEALTH PHYSICS SOCIETY*

Adopted: January 1996
Reaffirmed: March 2001
Revised: August 2004

If dose is < 100 mSv ...Take Care When Attempting to Assign Quantitative Risk to Individuals

Radiogenic Health Effects Have Not Been Consistently Demonstrated Below 10 Rem

Radiogenic health effects (primarily cancer) have been demonstrated in humans through epidemiological studies only at doses exceeding 5–10 rem delivered at high dose rates. Below this dose, estimation of adverse health effect remains speculative. Risk estimates that are used to predict health effects in exposed individuals or populations are based on epidemiological studies of well-defined populations (for example, the Japanese survivors of the atomic bombings in 1945 and medical patients) exposed to relatively high doses delivered at high dose rates. Epidemiological studies have not demonstrated adverse health effects in individuals exposed to small doses (less than 10 rem) delivered in a period of many years.

Limit Quantitative Risk Assessment to Doses at or Above 5 Rem per Year or 10 Rem Lifetime

In view of the above, the Society has concluded that estimates of risk should be limited to individuals receiving a dose of 5 rem in one year or a lifetime dose of 10 rem in addition to natural background. In making risk estimates, specific organ doses and age-adjusted and gender-adjusted organ risk factors should be used. Below these doses, risk estimates should not be used. Expressions of risk should only be qualitative, that is, a range based on the uncertainties in estimating risk (NCRP 1997) emphasizing the inability to detect any increased health detriment (that is, zero health effects is a probable outcome).

Have we evaluated total imaging doses for our patients?

Cumulative Imaging Radiation Exposure Following Breast-Conservation Therapy

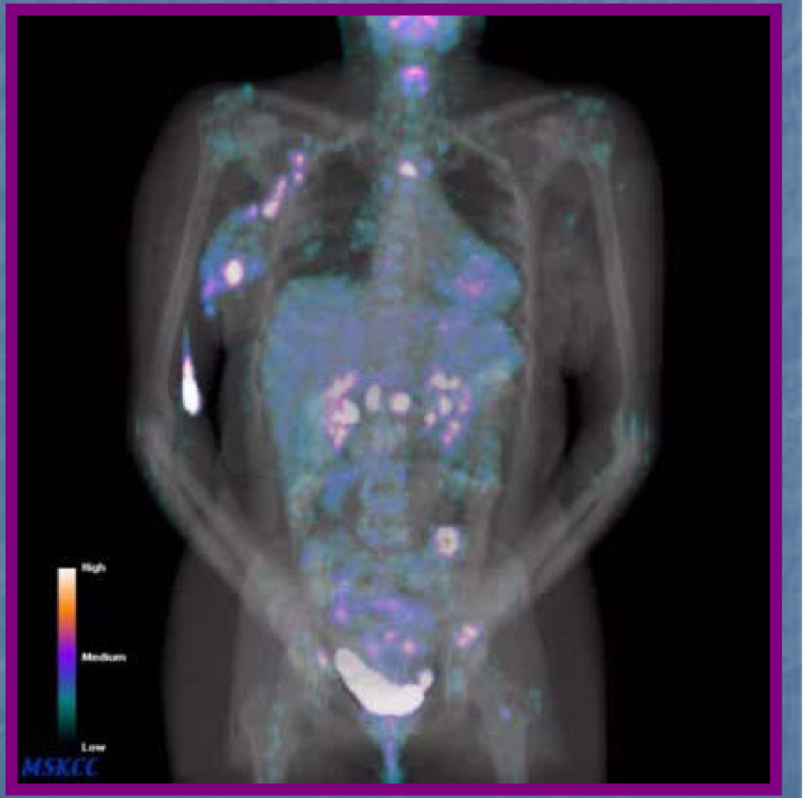
Jennifer L. Marti, MD[1], Lawrence T. Dauer, PhD[2], Michelle Stempel, MPH[1], Sujata Patil, PhD[3], Jennifer B. Kaplan, MD[4], Leslie L. Montgomery, MD, FACS[5]

	All patients N=68	1997 cohort N=43	2002 cohort N=25	1997 vs. 2002 p-value
5y Cumulative ED, mSv	4.56 (3.3-54.4)	4.65 (3.5-62.3)	4.55 (3.3-50.2)	0.56
Annual ED, mSv	0.92 (0.7-11.0)	0.97 (0.7-12.5)	0.91 (0.7-10.9)	0.85

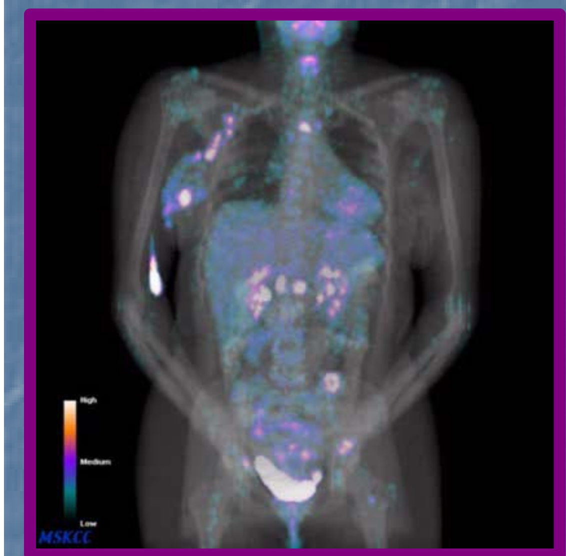
Annals of Surgical Oncology - pending

Are Diagnostic Doses Really a Concern for Our Patients?

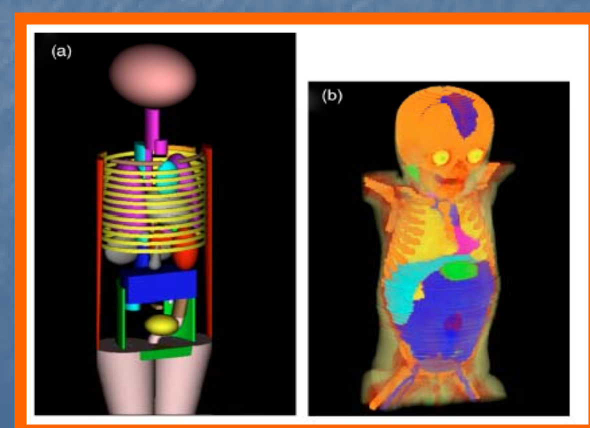
- Risks models based on dose averages and large populations.
- Risk vs. Benefit to Individual.
- Benefit must always be considered.
- Justification and Optimization are paramount



Justification

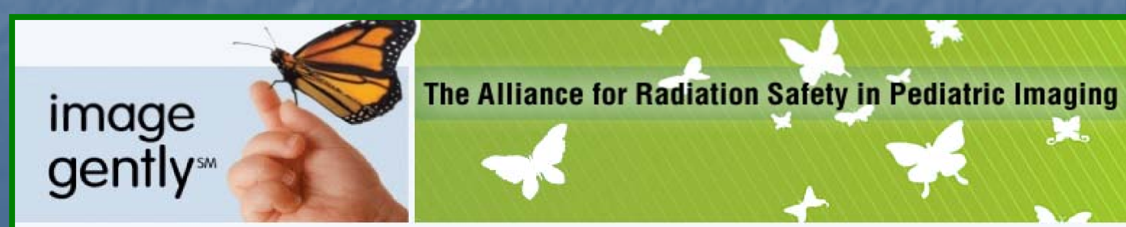


- In most symptomatic adults, radiation doses for diagnostic radiology procedures, including CT scans, result in extremely small risk, typically well-justified by the medical need.
- Risks are ~ 2-3 x larger for children.

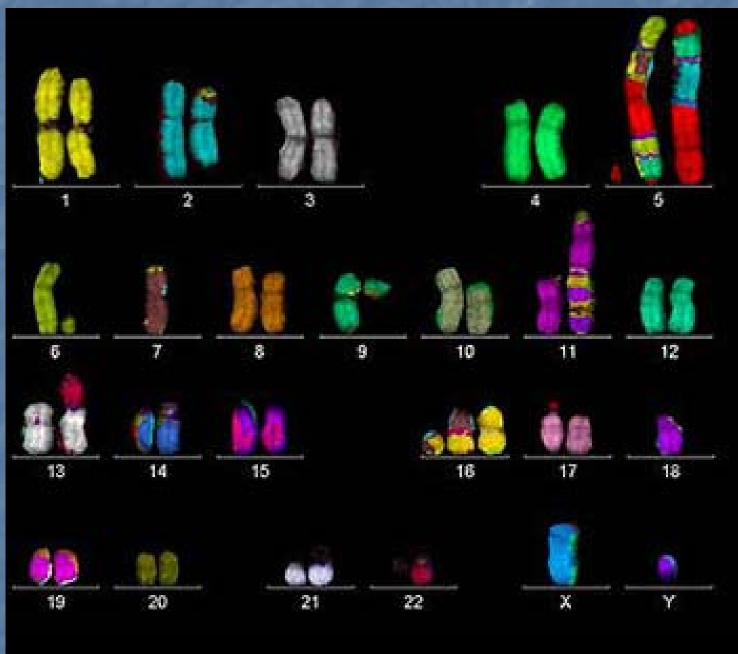


Suggestions

- NO radiation when you don't do the exam! Ensure each exam is justified.
- Carefully scrutinize screening protocols for 'healthy' subjects and post-therapy screening protocols for pediatric patients and patients with long-term survival expectation.
- Communicate dose and risk with staff (especially referring physicians) and patients.
- Medical Physics review/testing of final machine std protocols!!



Research Challenges – Some Questions Still Need Answers...



Human Chromosomes Showing DNA Damage From Radiation - Photo Credit: Massey University

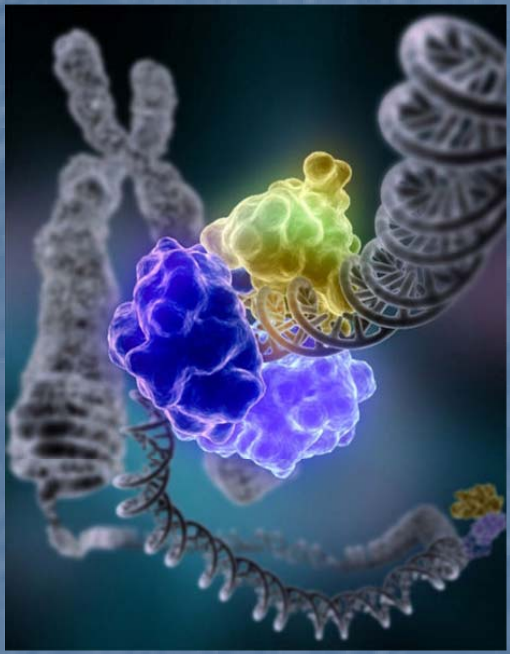
- Molecular markers of DNA damage at low doses?
- DNA repair fidelity and capacity for double and multiple strand breaks at low doses?
- Adaptation, hypersensitivity, bystander effects, hormesis, and genomic instability for radiation carcinogenesis?
- How to best communicate risk with patients?
- Benefits?

Radiation Hazard Index (RHI)

RHI	ED Range	Background Equivalent	Typical Examples	Risk Category
10	10,000Sv	-	Industrial Uses	10^{+2} Greater
9	1000Sv	-	Food Irradiation	10^{+1} Great
8	100Sv	Centuries	Radiotherapy: dose to tumor	10^{0} Major
7	10Sv	Century	Acute Total Body GI / Bone Marrow	10^{-1} Major
6	1Sv	Decades	Increased Ca Risk	10^{-2} Strong
5	100mSv	Decade	Dose Limits	10^{-3} Moderate
4	10mSv	Years	CT Nuclear Med Diag	10^{-4} Low
3	1mSv	Months	Abdominal x-ray	10^{-5} Very Low
2	0.1mSv	Weeks	Chest x-ray, Mammography	10^{-6} Minimal
1	0.01mSv	Days	Bone Density, Skull	~0 Negligible

Dauer,2008

Research Challenges – What Data are still Needed?



DNA Ligase Repairing Damage

- Prospective cohort and nested case-control studies of moderate-dose medical exposures.
- Epidemiological study consortia for medically exposed populations (CTs, Pediatrics, IR).
- Occupational low-dose studies.
- Exposed Population studies.
- Current Policies justified and optimized themselves?

Lawrence T. Dauer, PhD, CHP
Assistant Attending Health Physicist
Department of Medical Physics, MSKCC
dauerl@mskcc.org

Memorial Sloan-Kettering Cancer Center
The Best Cancer Care. Anywhere.

ICRP INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION

HPS Health Physics Society
Specialists in Radiation Safety • Founded 1956 • http://hps.org

American Association of Physicists in Medicine

NCRP National Council on Radiation Protection & Measurements

RSNA Promoting and developing the highest standards of radiology and related sciences through education and research

image gently℠ The Alliance for Radiation Safety in Pediatric Imaging

SOCIETY OF INTERVENTIONAL RADIOLOGY
Enhanced care through advanced technology

EPRI ELECTRIC POWER RESEARCH INSTITUTE