

# Risk and Dose Optimization in Computed Tomography

---

## William Hendee, PhD

Distinguished Professor  
Radiology, Radiation Oncology,  
Biophysics, Institute for  
Health Society  
Medical College of Wisconsin

Professor of Biomedical  
Engineering  
Marquette University

Adjunct Professor of Radiology  
Mayo Clinic

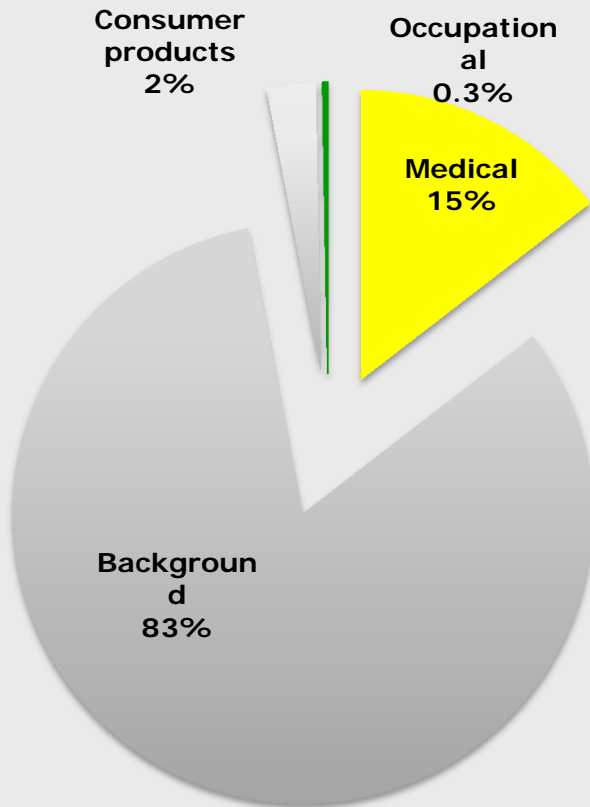
Adjunct Professor  
Electrical Engineering  
University of Wisconsin-  
Milwaukee

Adjunct Professor of Radiology  
University of New Mexico

Adjunct Professor of Radiology  
University of Colorado

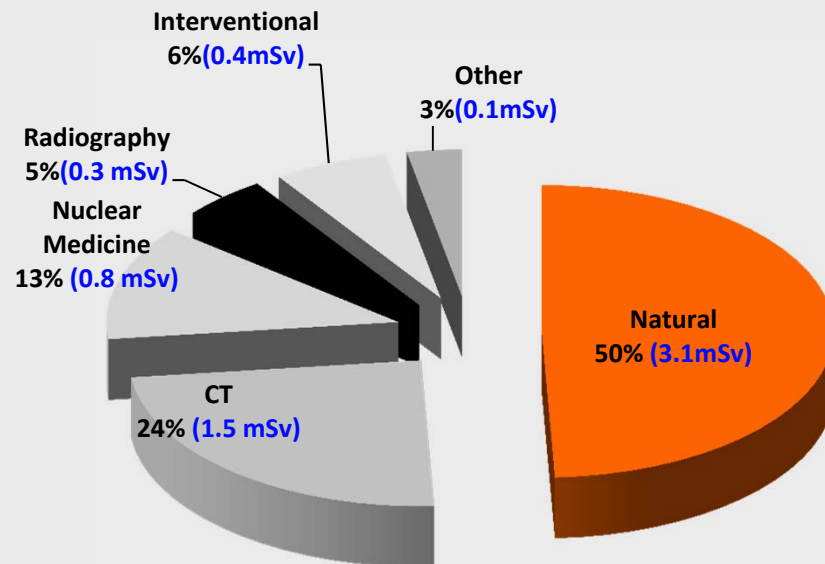
# Radiation Exposure to US Population from all Sources

US 1982 (NCRP 93)



Medical 0.54 mSv per capita  
Total 3.6 mSv per capita

US 2006 (NCRP 160)



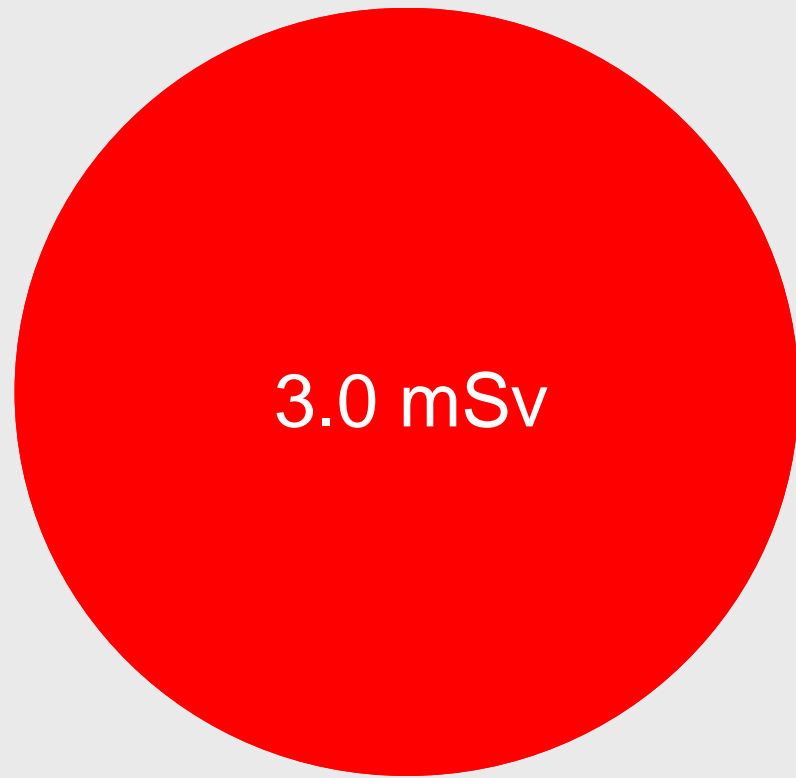
Medical 3.0 mSv per capita  
Total 6.2 mSv per capita

Per capita radiation dose from medicine has increased 560 percent



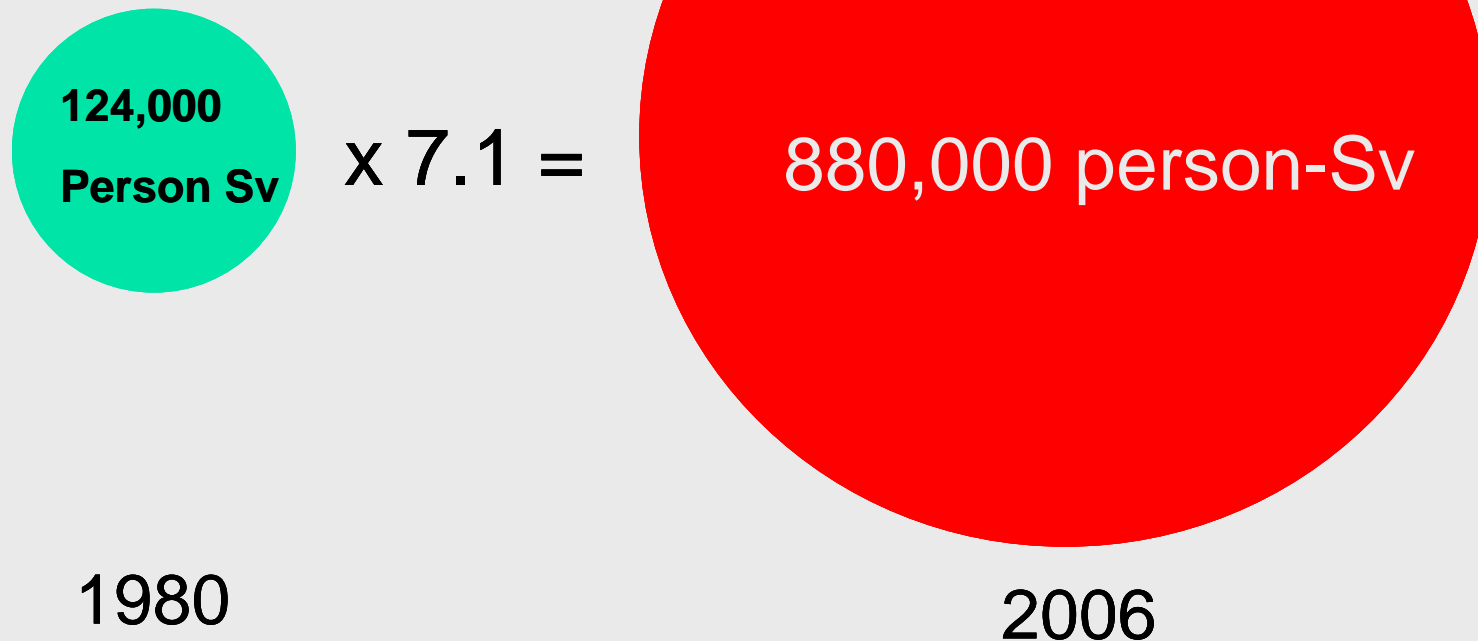
1980

$\times 5.6 =$

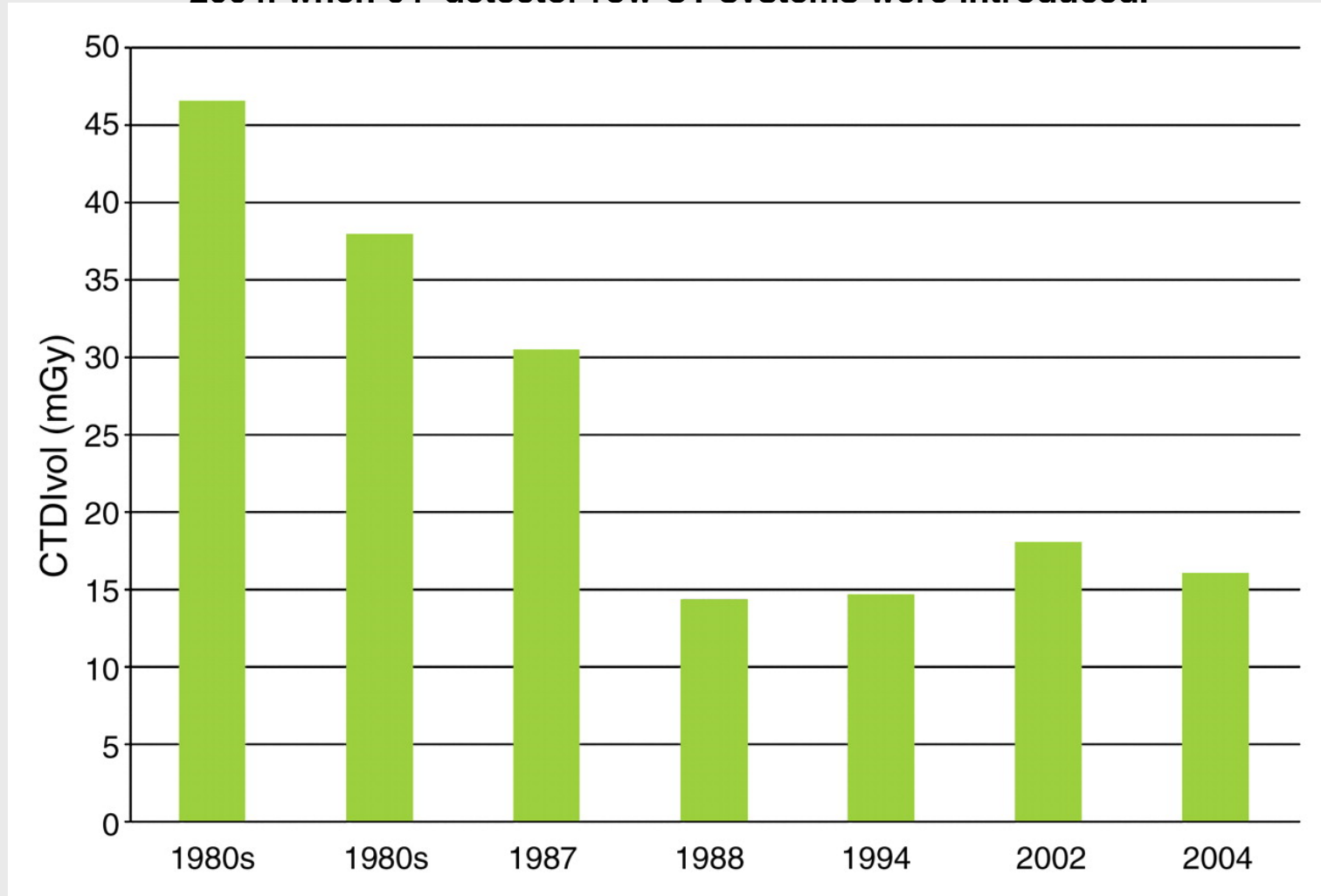


2006

Collective annual population dose from medicine has increased over 700 percent



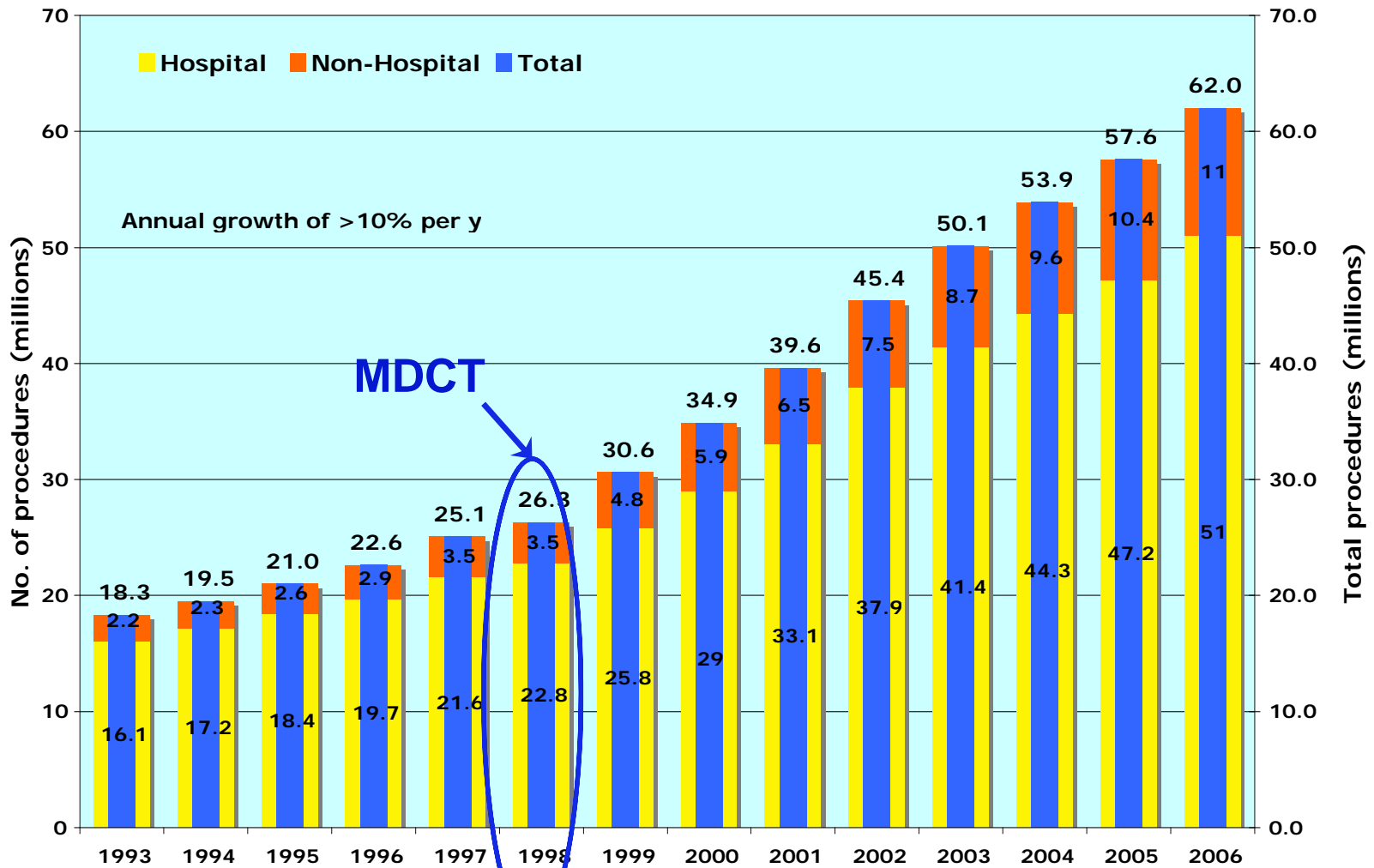
**Graph shows typical scanner output level (expressed as volume CT dose index [CTDIvol]) for a routine abdominal CT examination from the 1980s, when xenon detectors were used, to 2004. when 64–detector row CT systems were introduced.**



Hricak H et al. Radiology 2011;258:889-905

Radiology

# Number of CT Procedures in US



IMV Benchmark Reports on CT

2007: 68.7 million CT

# USA TODAY – DEC 14, 2009

---

CT scans deliver far more radiation than has been believed and may contribute to 29,000 new cancers each year, along with 14,500 deaths, suggest two studies in today's *Archives of Internal Medicine*.

## **Computed Tomography — An Increasing Source of Radiation Exposure**

David J. Brenner, Ph.D., D.Sc., and Eric J. Hall, D.Phil., D.Sc. N Engl J Med 2007; 357:2277-2284, [November 29, 2007](#)

1.5 – 2 % all cancers in United States caused by CT exams



# Sources of Data on Human Radiation Effects

---

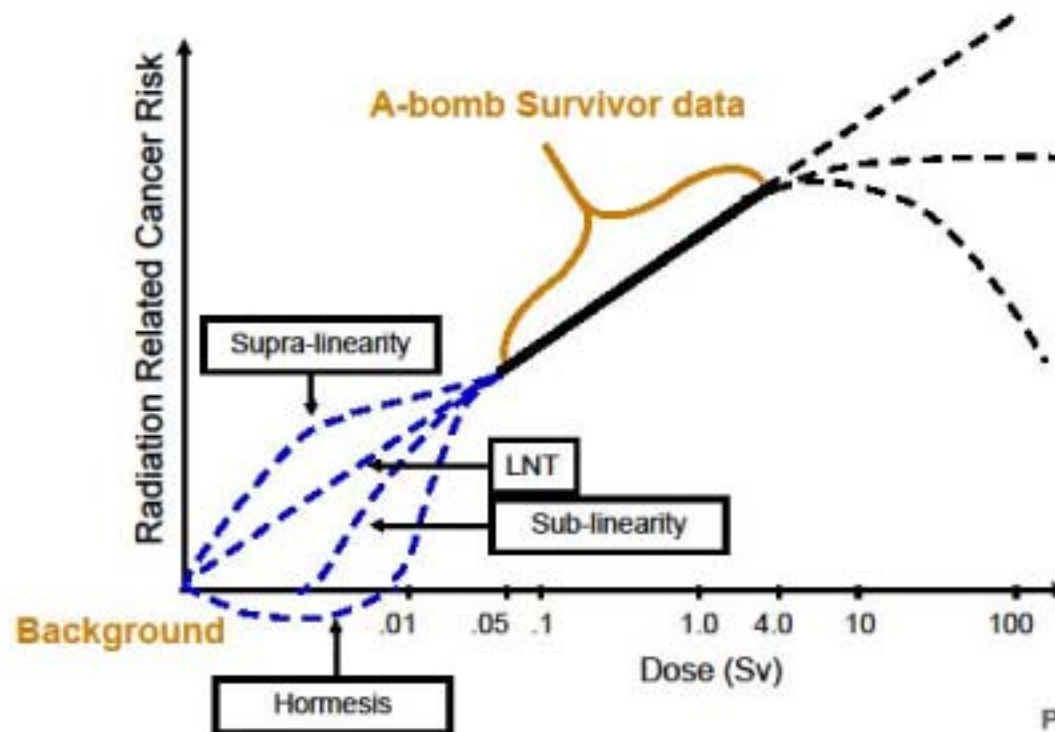
- RERF study of A-bomb survivors
- Occupational radiation studies
- Environmental radiation studies
- Populations near nuclear facilities
- Populations near A-bomb tests
- TMI and Chernobyl
- Natural background studies
- Medically-exposed populations

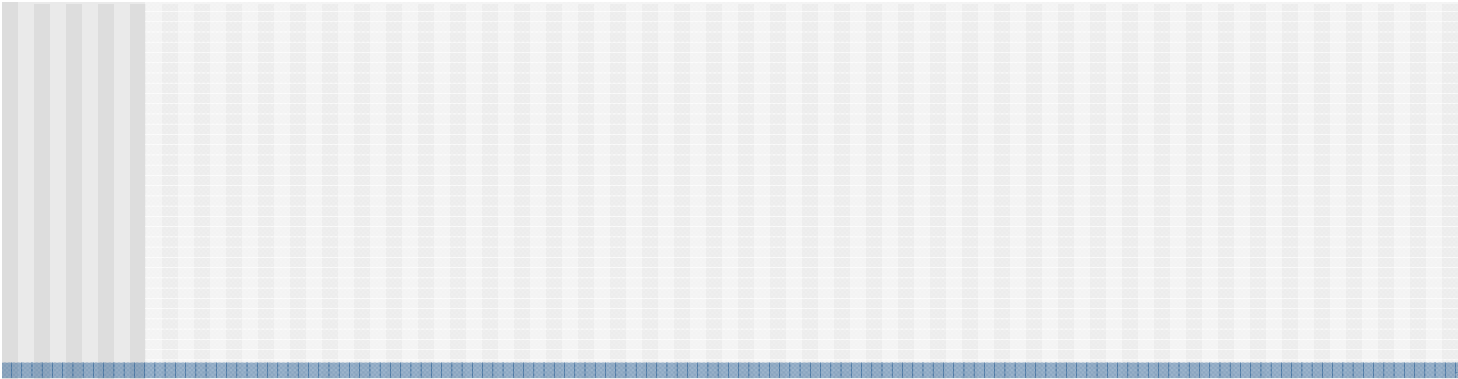
# Comparison of A-bomb Survivors to Medically-Exposed Persons

---

- Radiation LET
- Instantaneous whole-body exposures
- Additional health threats
- Additional health factors
- Absence of medical care

**The dilemma for radiation protection:** what is the scientific basis for radiation standards to protect the public from exposures to low levels of ionizing radiation (<0.1 Sv) where there are considerable uncertainties in the epidemiological data.





Effective dose: The dose which, if delivered uniformly to the whole body, would produce the same health consequences as those caused by a dose delivered to one or more specific organs

# Adult Effective Doses for Various CT Procedures

Examination	Effective dose (mSv)	Range in literature (mSv)
Head	2	0.9 – 4.0
Neck	3	...
Chest	7	4.0 – 18.0
Chest for Pulmonary Embolism	15	13 – 40
Abdomen	8	3.5 – 25
Pelvis	6	3.3 – 10
Three-phase liver study	15	...
Spine	6	1.5 – 10
Coronary angiography	16	5.0 – 32
Calcium scoring	3	1.0 – 12
Virtual colonoscopy	10	4.0 – 13.2

# LNT Model of Low-Dose Radiation Injury

---

- Introduced 1956 for genetic effects
- Intended for radiation protection standards
- Later adopted for cancer risk

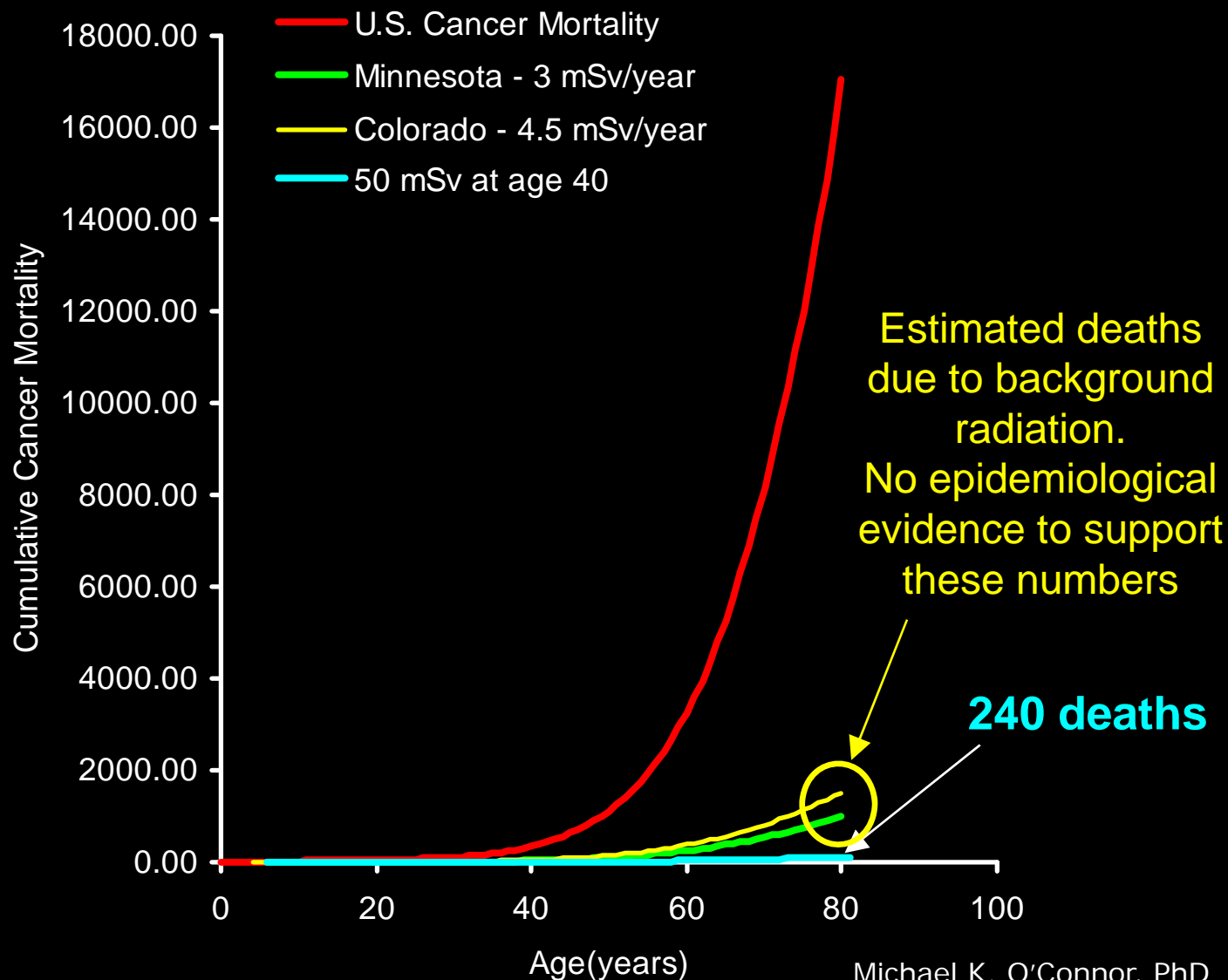


# Effective Dose: Recommendations of the ICRP. Publication 103 (2007)

---

Effective dose is intended for use as a protection quantity. The main uses of effective dose are the prospective dose assessment for planning and optimization in radiological protection, and demonstration of compliance with dose limits for regulatory purposes. Effective dose is not recommended for epidemiological evaluations, nor should it be used for detailed specific retrospective investigations of individual exposure and risk.

# Cancer mortality in 100,000 subjects





## **Where does the estimate of 29,000 cancers come from ?**

**Based on Table 12D BEIR VII, and risk estimates for 56,900,000 patients**

**For comparison: 9,700,000 people will die of cancer**

**IF they all lived in Minnesota, (bkg rad = 3 mSv)  
we would expect 576,000 deaths from background radiation**

**IF they all lived in Colorado, (bkg rad = 4.5 mSv)  
we would expect 863,000 deaths from background radiation**

**Differences in residence = 287,000 cancers, or ~10 CT scans/patient**

**TABLE 12-5A Lifetime Attributable Risk of Solid Cancer Incidence**

Cancer Site	Males			Females		
	LAR Based on Relative Risk Transport <sup>a</sup>	LAR Based on Absolute Risk Transport <sup>b</sup>	Combined and Adjusted by DDREF <sup>c</sup> (Subjective 95% CI <sup>d</sup> )	LAR Based on Relative Risk Transport <sup>a</sup>	LAR Based on Absolute Risk Transport <sup>b</sup>	Combined and Adjusted by DDREF <sup>c</sup> (Subjective 95% CI <sup>d</sup> )
<i>Incidence</i>						
Stomach	25	280	34 (3, 350)	32	330	43 (5, 390)
Colon	260	180	160 (66, 360)	160	110	96 (34, 270)
Liver	23	150	27 (4, 180)	9	85	12 (1, 130)
Lung	250	190	140 (50, 380)	740	370	300 (120, 780)
Breast				510 Not used	460	310 (160, 610)
Prostate	190	6	44 (<0, 1860)			
Uterus				19	81	20 (<0, 131)
Ovary				66	47	40 (9, 170)
Bladder	160	120	98 (29, 330)	160	100	94 (30, 290)
Other	470	350	290 (120, 680)	490	320	290 (120, 680)
Thyroid	32	No model	21 (5, 90)	160	No model	100 (25, 440)
Sum of site-specific estimates	1400	1310 <sup>e</sup>	800	2310 <sup>f</sup>	2060 <sup>e</sup>	1310
All solid cancer model <sup>g</sup>	1550	1250	970 (490, 1920)	2230	1880	1410 (740, 2690)

NOTE: Number of cases per 100,000 persons of mixed ages exposed to 0.1 Gy.

**...range of plausible values for LAR is labeled a “subjective confidence interval” to emphasize its dependence on opinions in addition to direct numerical observation (BEIR VII, page 278)**

# Risk Models

- **Lifetime Attributable Risk (LAR)**
  - “Because of the various sources of uncertainty it is important to regard specific estimates of LAR with a healthy skepticism, placing more faith in a range of possible values” (BEIR VII, page 278)
  - So how valid is the commonly-used factor of 5%/Sv increase in cancer risk?

# What Might the Upper Estimate of Risks Be?

---

- With assumptions of uniform population exposure and normal life expectancy etc.
  - Risk of fatal cancer from effective dose of 10 mSv from 1 CT or 1 nuclear medicine study is ~ 1/2000 or 0.05%
  - 60 million CTs annually in US *might* cause 30,000 fatal cancers
  - 20 million nuclear medicine exams annually in the US might cause 10,000 fatal cancers

# What is Wrong with the Analysis on the Previous Slide?

---

- Organ vs. whole-body dose
- Overestimation of dose
- Linear Risk Model
- Age distribution of patients
- Fatal cancer estimate (5%/Sv)
- Benefits not considered

# Radiation-Induced Cancer Deaths in Population

---

- Impossible to detect at doses < 100 mSv
- May be addressable in future by
  - New pathology criteria
  - Patient registries
  - Understanding cellular/molecular processes
  - Studies of sensitive sub-populations



# Sub-Populations of Radiation-Sensitive Individuals

---

- Ataxis telangiectasia
- Young women with scoliosis
- Tinea capitis patients

# Prediction of Hypothetical Cancer Deaths in Population

---

- No solid supporting data
- Predictions highly suspect
- Media attention
- Public anxiety
- Health effects of refused exams



# Health Physics Society Position

---

- Recommends against quantitative estimation of health risks below an individual dose of 5 rem (50 mSv) in one year or a lifetime dose of 10 rem (100 mSv) above that received from natural sources
- For doses below 5-10 rem risks of health effects are either too small to be observed or are nonexistent

# Cumulative Radiation Risk

---

- For patient with history of 1 scan, additional risk =  $5 \times 10^{-2}/\text{Sv}$
- For patient with history of 10 scans, additional risk =  $5 \times 10^{-2}/\text{Sv}$
- For patient with history of 100 scans, additional risk =  $5 \times 10^{-2}/\text{Sv}$

# Cumulative Radiation Risks in Medicine

---

- Cumulative dose estimates for patients are of little clinical relevance and never constitute a logical reason to avoid an imaging evaluation that is otherwise medically indicated.

D. Durand. AJR 2011;197;160-162

# Perception of Risk vs. Benefit



Richard J. Vetter, PhD