Growth of radiation uses in medicine

How big, how fast and why?
....Is it justified?

G. William Morgan Lecture
Health Physics Society
Oakland, CA, January 29, 2008

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NCRP SC 6-2
Radiation exposure of U.S. population 2006

Medical 1980

Natural

Technologically enhanced

Occupational

Report probably to be published in 2008
Medical Subgroup SC 6-2

- B. Thomadsen, Chairman, Univ of Wisc.
- M. Bhargavan, American College of Radiology
- D. Gilley, State of Florida
- J. Gray, DIQUAD, LLC
- J. Lipoti, State of New Jersey
- M. Mahesh, Johns Hopkins Univ.
- J. McCrohan, U.S. F.D.A.
- F. Mettler, Univ of New Mexico VA
- T. Yoshizumi, Duke Univ.

- M. Rosenstein, Scientific NCRP Consultant
- K. Kase, Stanford SC 6-2 Chair
Assumptions and Issues

• Benefit exceeds risk  (maybe)

• RBE = 1  (…..or more)

• Weighting Factors: Used ICRP 60 (1990). Past reports used older ICRP 26 (1977) and new factors are suggested.  
  (not a big deal for most exams)
Major changes in imaging over the last decade that involve substantial radiation doses

- New uses of CT
  - Clinical
  - Screening
  - CT combined with other procedures
- Cardiac nuclear medicine
- Digital radiography
- Increasing use of radiation by non-radiologists
## Preliminary Results (U.S. 2006)

<table>
<thead>
<tr>
<th>Service</th>
<th>Number procedures</th>
<th>%</th>
<th>Collective dose (Person-Sv)</th>
<th>%</th>
<th>Per capita (mSv)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radiography</td>
<td>244 million</td>
<td>64</td>
<td>88,300</td>
<td>10</td>
<td>0.3</td>
</tr>
<tr>
<td>Interventional</td>
<td>13 million</td>
<td>3</td>
<td>112,000</td>
<td>13</td>
<td>0.4</td>
</tr>
<tr>
<td>CT</td>
<td>67 million</td>
<td>18</td>
<td>440,000</td>
<td>50</td>
<td>1.5</td>
</tr>
<tr>
<td>Mammography</td>
<td>34 million</td>
<td>9</td>
<td>6,000</td>
<td>0.7</td>
<td>0.01</td>
</tr>
<tr>
<td>Dental</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nuclear Medicine</td>
<td>18 million</td>
<td>5</td>
<td>231,000</td>
<td>26</td>
<td>0.8</td>
</tr>
<tr>
<td>Radiotherapy</td>
<td>1 million pts</td>
<td>NA</td>
<td>NA</td>
<td></td>
<td>--</td>
</tr>
</tbody>
</table>

Total x-ray + NM = ~ 375 million  ~ 880,000  ~ 3.0
<table>
<thead>
<tr>
<th>Procedure</th>
<th>Number millions</th>
<th>%</th>
<th>Collective dose Person Sv</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head Face</td>
<td>1.9</td>
<td>0.7</td>
<td>421</td>
<td>0.4</td>
</tr>
<tr>
<td>Chest</td>
<td>126</td>
<td>46</td>
<td>12,585</td>
<td>13.3</td>
</tr>
<tr>
<td>Abdomen</td>
<td>14.9</td>
<td>5.4</td>
<td>10,475</td>
<td>11.1</td>
</tr>
<tr>
<td>Pelvis/Hips</td>
<td>20</td>
<td>7.2</td>
<td>13,156</td>
<td>14.0</td>
</tr>
<tr>
<td>Extremities</td>
<td>57</td>
<td>20.5</td>
<td>174</td>
<td>0.2</td>
</tr>
<tr>
<td>Spine</td>
<td>18</td>
<td>6.5</td>
<td>18,600</td>
<td>19.7</td>
</tr>
<tr>
<td>Mammography</td>
<td>34</td>
<td>12.2</td>
<td>5,984</td>
<td>6.3</td>
</tr>
<tr>
<td>IVP</td>
<td>1.2</td>
<td>0.4</td>
<td>3,540</td>
<td>3.8</td>
</tr>
<tr>
<td>Upper GI</td>
<td>4</td>
<td>1.4</td>
<td>24,150</td>
<td>25.6</td>
</tr>
<tr>
<td>Barium enema</td>
<td>0.65</td>
<td>0.2</td>
<td>5,200</td>
<td>5.5</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>~278</td>
<td></td>
<td>~94,000</td>
<td></td>
</tr>
</tbody>
</table>
Per capita radiation dose from medicine has increased 560 percent

\[0.54 \text{ mSv} \times 5.6 = \approx 3.0 \text{ mSv}\]

These results have not been reviewed and approved by Council.
Not to be disseminated or referenced
Collective annual population dose from medicine has increased over 700 percent.

$124,000 \times 7.1 = 880,000 \text{ person-Sv}$

These results have not been reviewed and approved by Council. Not to be disseminated or referenced.
Preliminary estimate of changes in U. S. medical radiation exposure

U.S. 1980

Natural 2.8 mSv
Medical 0.54 mSv
Total 3.6 mSv per capita

U.S. 2006

Interventional 0.4 mSv
Radiography 0.3 mSv
Nuclear medicine 0.8 mSv
CT scanning 1.5 mSv
Medical ~3.0 mSv
All other ?? mSv
Natural 3.0
Total ~ 6.0
2.4, 2.8, 3.0 mSv

Why does the value of natural background keep changing .... even though in reality it has not changed for over 1 million years?

Ans: physicists
Preliminary estimate of changes in U. S. medical radiation exposure

U.S. 1980

- Natural 2.8 mSv
- Medical 0.54 mSv
- All other

Total 3.6 mSv per capita

U.S. 2006

- Natural 2.4 UNSCEAR
- Medical ~3.0 mSv
- Interventional 0.4 mSv
- Radiography 0.3 mSv
- Nuclear medicine 0.8 mSv
- CT scanning 1.5 mSv
- All other ?? mSv

Total ~ 5.4
Computed tomography (CT scan)

Recent advances in machine technology have led to more applications and markedly increased usage.
CT scans by year in US (millions)

Annual growth > 10%/yr
U.S. population < 1%/yr

No. of procedures (millions)

- 1993: 18.3
- 1994: 19.5
- 1995: 21.0
- 1996: 22.6
- 1997: 25.1
- 1998: 26.3
- 1999: 30.6
- 2000: 34.9
- 2001: 39.6
- 2002: 45.4
- 2003: 50.1
- 2004: 53.9
- 2005: 57.6
- 2006: 62.0
## Preliminary Results for CT (U.S. 2006)

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Number (millions)</th>
<th>%</th>
<th>Collective dose person Sv</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head</td>
<td>19</td>
<td>28</td>
<td>38,000</td>
<td>8.7</td>
</tr>
<tr>
<td>Chest</td>
<td>10.6</td>
<td>16</td>
<td>74,300</td>
<td>17.0</td>
</tr>
<tr>
<td>Abd/Pelvis</td>
<td>25.4</td>
<td>38</td>
<td>254,000</td>
<td>58</td>
</tr>
<tr>
<td>Extremity</td>
<td>3.5</td>
<td>5</td>
<td>515</td>
<td>0.1</td>
</tr>
<tr>
<td>CT Angiogram</td>
<td>4.3</td>
<td>6</td>
<td>56,000</td>
<td>12.8</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>4.2</td>
<td>6</td>
<td>154,730</td>
<td>3.4</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>67</strong></td>
<td><strong>100</strong></td>
<td><strong>438,000</strong></td>
<td><strong>100</strong></td>
</tr>
</tbody>
</table>

Effective dose per capita 1.46 mSv
Why has there been such spectacular growth in procedures ..

........and such an increase in dose ??
Single slice CT scanner

Tube rotates, image is obtained, then table moved incrementally and another tube rotation and another image obtained. Scan time ~ 10-20 minutes
Helical (spiral) single slice CT scanner

Tube continuously rotates and table has constant feed. **Scan time ~10-30 seconds**
Multislice multidetector helical CT scanner

- x-ray tube
- Patient table
- Constant motion
- 16-300 detectors

Constant tube rotation, constant table feed. More detectors.

Scan time 0.3-5 seconds. Now 300 slices/images in 0.3 second
CT scanning delivers high radiation doses

- “The absorbed dose to tissues from CT can often approach or exceed the levels known to increase the probability of cancer as shown in epidemiological studies” ICRP 2002

Unusual case of hair loss from excessive dose during CT angiograms
Is there a cancer risk from CT?

A-bomb data show a statistically significant increase at > 50 mSv

Organ dose (mSv) vs Relative risk

1 CT scan sequence

3-phase CT liver scan

4-5% of CT scan patients
Comparison of effective doses

- **0.2 mSv**
- **0.7 mSv**
- **7 mSv**
- **14 mSv**
New widespread uses of CT

- **Clinical**
  - Appendicitis
  - Renal colic/stones
  - Pulmonary embolism
  - Trauma
- **Screening**
  - Coronary arteries
  - Colonoscopy
  - Lung cancer

- Most of these improve confidence in diagnosis
- Few of these uses have been studied sufficiently to show a significant change in patient outcome
- They are clearly easy to interpret and fast to do
CT Use for Acute Appendicitis

- Typical clinical symptom triad absent in 50%
- Before CT~ 15-20% of operations resulted in removal of a normal appendix
- CT accuracy 97% and now only 3% of operations yield normal appendix
- CT has a higher accuracy for alternative diagnoses
Appendicitis
Renal stones/colic

Intravenous urogram (IVP)

Requires injection of intravenous contrast

Contrast reactions in 5% of patients

Death from contrast 1/40,000 to 1/100,000

Procedure takes 30 minutes
Dilated ureter

4mm stone in distal ureter

Stranding and edema around kidney

4mm stone in distal ureter

Dilated ureter
CT scanning for renal colic

- Intravenous urogram rarely done anymore
- CT scan without intravenous contrast takes 30 seconds with an accuracy of 97%
- Effective radiation dose 14 mSv
- Repeated examinations common.
Relative magnitude of individual doses

- Annual natural background
- Annual public dose limit ICRP
- 1 Chest x-ray
- 1 Abdomen x-ray
- 1 Head CT
- 1 Chest CT
- 1 Abd/pelvis CT
- Avg annual dose Chernobyl contam area 0-10 yr

Effective dose (mSv)
Many patients have more than CT examination.

This 35 year old had 18 CT exams.
Nuclear medicine lung perfusion scan

Chest CT scan with intravenous contrast

Reduced blood flow to one lung - nonspecific

Large clot in right main pulmonary artery - clear diagnosis
CT scanning of the chest for pulmonary embolism

• Breast dose in thorax CT may be as much as 30-50 mGy, even though breasts are not the target of imaging procedure.

• Breast dose from chest CT equals that from about 10-15 sets of 2 view mammograms.

• Often done on younger patients.

• Now CT is routine for PE and in the U.S. has generally replaced nuclear medicine except for pregnant patients and those with contrast allergies.
Trauma

With new multi-slice CT scanners, head, neck, chest abdomen and pelvis can be scanned in 10-30 seconds.

Many significant findings are seen such as brain hemorrhage, small pneumothoraces and liver lacerations which are difficult or impossible to see on plain x-rays.
Relative magnitude of individual doses

- **Effective dose (mSv)**

- **Annual natural background**
- **Annual public dose limit ICRP**
- **1 Chest x-ray**
- **1 Abdomen x-ray**
- **Trauma CT head>pelvis**
- **Avg annual dose Chernobyl contam area 0-10 yr**
- **Avg total 0-10 yr dose Chernobyl contam area**
Coronary artery calcium scoring and screening

Calcified left anterior descending coronary artery
Coronary artery calcium scoring

• Calcification score is related to risk of future cardiac event

• But.. 50% of persons with myocardial infarct have “soft plaque” and no calcification

• Potential U.S. market > 50 million persons

• Radiation effective dose 3 mSv

• If used typically combined with other risk factors

• Not currently recommended for screening but it is still widely advertised and practiced in the U.S.
Coronary artery stenosis

Contrast invasive coronary angiogram

3-D CT scan
CT coronary angiography

- Really needs 64-slice CT scanner. 16-slice scanner is marginally adequate.
- Not indicated for those needing bypass surgery.
- Can be used to assess patency of grafts and stents.
- Radiation effective dose: 16 mSv.
- Is now being used to examine patients with angina although value not proven.
Relative magnitude of individual doses

- Effective dose (mSv)

- Annual natural background
- Annual public dose limit ICRP
- 1 Chest x-ray
- CT calcium scoring
- CT coronary angio
- Avg annual dose Chernobyl contam area 0-10 yr

Bar chart showing the relative magnitude of individual doses.
CT screening for lung cancer and followup of lung nodules

Nodules as small as 2-3 mm are easily seen on CT. On regular chest x-ray most non-calcified nodules need to be 8-10 mm to be reliably visualized.
CT screening for lung cancer

• 70% of smokers have lung nodules

• < 0.1 % are cancer (< 1/1000)

• ~ 1-2 % nodule resection mortality
  • If surgery were done on 1000 nodules 10-20 deaths might occur to find 1 cancer

• Do not rescan < 4mm nodules in low risk persons

• Scan at 3, 6, 12 and 24 months in others
  • Radiation effective dose 7 mSv per scan
Is there really a benefit??

Henschke et.al. NEJM 2006
CT scanning can prevent 80% of lung cancer deaths

Bach PB et.al. JAMA 2007
144 cancers found 44 expected
No reduction in mortality
38 deaths vs 38.8 expected
Relative magnitude of individual doses

Effective dose (mSv)

- Annual natural background
- Annual public dose limit ICRP
- 1 Chest x-ray
- 1 Abdomen x-ray
- 1 Chest CT
- Avg annual dose Chernobyl contam area 0-10 yr
CT (virtual) colonoscopy

CT scout image

3-D image of colon

CT virtual fly-through

Fiber-optic colonoscopy
CT colonoscopy screening

- Requires laxative preparation
- Residual fecal material a problem
- Accuracy poor for lesions < 10 mm
- Variability in interpretation
- Radiation effective dose 4-13 mSv
- 20-30% will be positive and need fiber-optic colonoscopy for biopsy
- Potential market in US 50+ million persons
- Not yet widely used
Relative magnitude of individual doses

- Annual natural background
- Annual public dose limit ICRP
- 1 Chest x-ray
- 1 Abdomen x-ray
- CT colonoscopy
- Avg annual dose Chernobyl contam area 0-10 yr

Effective dose (mSv)
Incidental findings on CT scans

- Gallstones: ~5%
- Renal cysts: ~50% older
- Fatty liver: ~5-10%
- Congenital: ~5%
10-fold variation in CT scan doses

S. Stern, USFDA
Isn’t the radiation risk lower because patients are older and don’t live as long?

- Probably not much lower (maybe 35%)
- In the U.S. less than 5% of all examinations occur in the year prior to death
- A 65 year old has a 50/50 chance of making it to age 85
CT scans of abdomen and pelvis
Exam distribution vs U.S. population

<table>
<thead>
<tr>
<th>Age Range</th>
<th>% of Population</th>
<th>% of CTs</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-10</td>
<td>15.0%</td>
<td>1.3%</td>
</tr>
<tr>
<td>11-17</td>
<td>10.1%</td>
<td>2.2%</td>
</tr>
<tr>
<td>18-24</td>
<td>10.0%</td>
<td>3.7%</td>
</tr>
<tr>
<td>25-34</td>
<td>13.7%</td>
<td>7.2%</td>
</tr>
<tr>
<td>35-44</td>
<td>12.4%</td>
<td>13.7%</td>
</tr>
<tr>
<td>45-54</td>
<td>15.3%</td>
<td>12.4%</td>
</tr>
<tr>
<td>55-64</td>
<td>18.0%</td>
<td>15.3%</td>
</tr>
<tr>
<td>65-74</td>
<td>19.0%</td>
<td>18.0%</td>
</tr>
<tr>
<td>75-84</td>
<td>19.4%</td>
<td>19.4%</td>
</tr>
<tr>
<td>85 and older</td>
<td>16.1%</td>
<td>19.0%</td>
</tr>
</tbody>
</table>

2003
Children are likely to be at 2-5x higher cancer risk from radiation than are adults. Adult CT technical factors are often used inappropriately on children.
Nuclear medicine visits by year
U.S. (millions)

Currently approximately 1 nuclear medicine procedure annually per 15 persons

5% Growth annually

0 5 10 15 20
10.2 10.5 10.9 11.8 12.6 13.5 14.5 14.9 15.7 16.5 17.2
Cardiac nuclear medicine

Ischemic area seen at stress fills in at rest
Cardiac nuclear medicine (wall motion)

Diastole

Systole

Poor motion of inferior wall due to prior myocardial infarct
Cardiac nuclear medicine

- Techniques have been available for over a decade but number of procedures has almost doubled
- Cardiologists now own equipment and self-refer almost 2/3 of the cases
- New for-profit “Heart Hospitals” in almost every city in the U.S.
- Potential market > 50 million persons
- Radiation effective dose 10 mSv
Effective dose (mSv)

Relative magnitude of individual doses

- Annual natural background
- Annual public dose limit ICRP
- 1 Chest x-ray
- 1 Abdomen x-ray
- Cardiac stress/rest perfusion
- Avg annual dose Chernobyl contam area 0-10 yr
- Avg total 0-10 yr dose Chernobyl contam area

Effective dose (mSv)
Combined CT and other modalities
Post colon cancer surgery
Rising tumor marker (CEA)
Positron emission (PET) scan

$^{18}$F-FDG
fluorodeoxyglucose

Heart
Kidneys
Bladder
Combined PET/CT scan
Lung metastasis from laryngeal cancer

CT scan

PET/CT scan

Nodules must be > 8 mm to be reliably visualized
What is the effective dose from one PET/CT scan?

<table>
<thead>
<tr>
<th>Component</th>
<th>Dose (mSv)</th>
</tr>
</thead>
<tbody>
<tr>
<td>740 MBq $^{18}$F-FDG</td>
<td>14</td>
</tr>
<tr>
<td>Head CT</td>
<td>2</td>
</tr>
<tr>
<td>Neck CT</td>
<td>3</td>
</tr>
<tr>
<td>Chest CT</td>
<td>7</td>
</tr>
<tr>
<td>Abdomen CT</td>
<td>8</td>
</tr>
<tr>
<td>Pelvis CT</td>
<td>6</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>40</strong></td>
</tr>
</tbody>
</table>
Effective dose (mSv)

Annual natural background
Annual public dose limit ICRP
1 Chest x-ray
1 Abdomen x-ray
Whole body PET/CT

Relative magnitude of individual doses

Avg annual dose Chernobyl contam area 0-10 yr
Avg total 0-10 yr dose Chernobyl contam area

Effective dose (mSv)
So how big is 880,000 person-Sv?
Collective population doses: Comparison

- ~400,000 person-Sv worldwide over all time from entire Chernobyl release*

- ~880,000 person-Sv *annually* from radiology and nuclear medicine in U.S.

- ~900,000 person-Sv *annually* from natural background radiation (assuming old NCRP 100 calculations)

* UNSCEAR 2007
Is there any potential detriment from 880,000 person-Sv?

 Depends who you talk to…

 … but the answer is “yes” for all of medicine if you subscribe to LNT hypothesis

 … and yes for multiple CT or NM scans regardless of your LNT beliefs
Does anybody, or should anybody, regulate this, the largest (and controllable) source of radiation exposure?

The largest radiation source in the U.S. remains largely unregulated and appears likely to continue to grow with minimal constraints.
Manufacturers are now advertising directly to self-referring clinicians.

<table>
<thead>
<tr>
<th>Procedures Per Day</th>
<th>Days Per Month</th>
<th>Average CPT</th>
<th>Income</th>
<th>FMVL Cost</th>
<th>ROI* Per Month</th>
<th>ROI for 5 Years</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.8</td>
<td>20</td>
<td>$220</td>
<td>$7,950</td>
<td>$7,950</td>
<td>Break Even</td>
<td>Break Even</td>
</tr>
<tr>
<td>5</td>
<td>20</td>
<td>$220</td>
<td>$22,000</td>
<td>$7,950</td>
<td>$14,050</td>
<td>$843,000</td>
</tr>
<tr>
<td>10</td>
<td>20</td>
<td>$220</td>
<td>$44,000</td>
<td>$7,950</td>
<td>$36,050</td>
<td>$2,163,000</td>
</tr>
</tbody>
</table>

Sample computation – Basic SOMATOM Spirit configuration, based on a 5-year Fair Market Value Lease (FMVL). Prices will vary with additional options. Please consult your Siemens Account Executive for details.
*Return on Investment.
Gift Certificates for Radiation Exposure ????

http://www.jeffxray.com/handler.cfm?event=practice,template&cpid=10192

CT Scan

Procedure Name:
Computed Tomography

Description:
A CT scan, or CAT scan, is a common term for computerized spiral tomography, a painless diagnostic imaging test that displays two-dimensional images of internal structures of the body on a computer screen. This test often takes less than 30 minutes to perform. Patients can receive a CT scan on an outpatient basis or as part of an inpatient hospital stay.

Basic Facts:

- Computed tomography (CT) scanners are diagnostic testing devices that use x-rays to obtain horizontal and vertical cross-sectional views of internal areas of the body. In addition to creating diagnostic images, the CT scanner can be used to guide needle or catheter placement.
- The CT scanner consists of a gantry, a control console, and a computer that displays images on a monitor.
- CT scans have a fine degree of detail.

CT scans can be taken of many sections of the body, including the abdomen, chest, and brain. The images come from the reflection of x rays off tissues of varying densities. Sometimes a contrast dye is given to a patient intravenously, rectally, or orally to make hollow or fluid-filled structures such as blood vessels more visible. The use of contrast material during CT scanning...
How does the typical physician view radiation protection?

How bad is the patient bleeding?

Will the test or therapy affect outcome?

Is it available?

What is my experience?

What is the downside if I don’t order it?

Have I seen anything in the literature lately?

What is my gut feeling?

Radiation risk?? Is that an issue??
My observations

• Have we substantially increased the dose medical diagnostic uses of radiation? Absolutely ~ 500 – 700 percent

• There is no question that serial CT and NM doses are in the range known to increase the probability of cancer

• Do we think we are practicing better medicine? Yes
My observations

- Is there a radiation risk from these procedures? *Probably (low individual risk but possibly large numbers)*

- Do most physicians have any idea of the magnitude of increased medical radiation dose or possible risk? *Definitely not*

- Have we really shown an evidence-based benefit for any these procedures? *Certainly not for most*
My observations

• Do most physicians have any idea of the magnitude of increased medical radiation dose or possible risk? **Definitely not**

• Can these doses be substantially reduced without losing diagnostic accuracy? **Absolutely**

• Remember: medical radiation usually has direct benefit to individual. **We must be careful not to eliminate needed exams**
Are we safer?
Is all this justified??

You decide
Thank you